VOL. XII NO. 4

THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

APRIL 1923

SOCIETY OF AUTOMOTIVE ENGINEERS INC.
29 WEST 39TH STREET NEW YORK

If The Car Spring Does Not Yield, Then The Bump Is Transmitted To The Car Body. There Are No Two Ways About That.

THE most casual observer of the laws of physics will recognize the above truth. Then why make car springs stiff? Why not make them soft enough so that each *little* bump as well as each big bump will find it easier to bend the spring than to punch the car body. In short, why not save the car and passengers by inserting, between them and the road, a cushion which *is* a cushion.

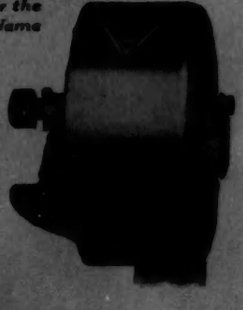
Naturally, with a *soft* cushion you must provide enough clearance so that the spring will not "bottom" when driving over the *big* bumps. Also you will want to watch the matter of elastic limit. And also you will have to do some thinking about the hook-up of your brake rods and your steering mechanism.

All of this means a little "headache" for the Engineer. You might just as well get started though. If for no other reason—the other fellow has *already* started—and motorists are not going to ride behind your name-plate and be bumped when they find they can ride behind some other name-plate and be *cushioned*.

And then we come to the wonderful vibrations, small and large, of such a set of springs. To overcome these vibrations you will not want to dampen the *action* of the springs because that would again stiffen them and stiffness is just what you are trying to get away from. The way to dampen these vibrations is to attack the *reaction*. Naturally, more dampening is required when the vibrations are violent than when they are mild.

Now we are getting down to Stabilators. But what's the use worrying about taking care of vibrations or reactions so long as your cars are equipped with springs which are so stiff that only the big bumps can *cause* them to vibrate.

Look for the Silver Name Plate



Exactly opposite to snubbing

In checking spring recoil, Stabilators work exactly opposite to the snubbing principle. Instead of checking with a jerk at the tail end of the recoil movement, Stabilators get on the job at the very beginning of the movement and smoothly ease you back to normal. Results produced by the one method give no conception of those produced by the other. They are different to the point of absolute oppositeness.

JOHN WARREN WATSON COMPANY
Twenty-Fourth and Locust Streets
Philadelphia Pa.

WATSON STABILATORS

RESIST EACH RECOIL IN PROPORTION TO ITS FORCE

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Chronicle and Comment

Painting Troubles

ONE of the most general manufacturing problems encountered of late has been that epitomized as paint-trouble. The Detroit Section devoted its March meeting to this subject and the wide-spread interest in it is reflected in the attendance which exceeded 250. A feature of the meeting was the rapid-fire answering of practical questions by the speaker, L. V. Pulsifer. These questions with the answers form a valuable paper on painting that is recommended to the members for careful reading. The report will be found on p. 335.

Farm Tractor Meeting

THE Society will hold its annual Tractor Meeting at the Auditorium Hotel, Chicago, April 19. Engineering sessions have been scheduled in the morning and afternoon with an informal Tractor Luncheon at noon. One technical paper will be read at each of the sessions. The all-purpose type of farm tractor will be the subject discussed in the morning session. Constructive engineering criticism based on the Nebraska tractor tests will be presented in the afternoon. Both papers will have a distinct bearing upon the design of the farm tractor of the future. Further details of this meeting are given on p. 398.

Automotive Traffic

OUR trucks move 1,250,000,000 tons of freight a year. Allowing for 10,000,000 passenger cars in daily use, on the basis of 2½ persons riding in a car, we have 25,000,000 automobile passengers daily. Seventy-two per cent of all the automobiles go into population points of 50,000 or less, 52 per cent into points of 10,000 or less and 30 per cent into points of 5000 or iess.

We have $1,500,000,000 invested in our plants. We produce more than 2,000,000 units of transportation yearly. The wholesale value of cars, trucks, tires and accessories, in 12 months, amounts to $3,500,000,000. We expend for material $1,250,000,000. We pay $350,000,000 of wages to 250,000 factory employes, and open a means of livelihood to perhaps as many more associated with dealer plants, garages, repair shops and filling stations.—George M. Graham.

Automotive Transportation Meeting

A NATIONAL meeting of the Society will be featured this month devoted entirely to the topic of automotive transportation. It is scheduled in Cleveland, April 26 to 28, and will include several professional meetings, the Motor Transport Dinner and a group of factory visits. The attractive program of papers printed on p. 399 reflects the scope and importance of this meeting. Some of the Country's ablest transport authorities will read their opinions on automotive-transportation problems. The motor truck, motorbus and taxicab will each receive attention. The meeting is of primary importance to everyone in the automotive-transport business be he engineer, vehicle builder or operator. Reduced railroad fares and the central location of the meeting place render attendance inexpensive and convenient.

S. P. A. E.

HARTLEY MANNERS, in a fit of irritation, has called our theatrical managers glorified janitors. How can glory be added to him in whose person all known glories, splendors and powers are already centralized? What Mr. Manners really meant was that the managers are half-hearted janitors, with the inferiority complex, who perform the work of a janitor but dare not assume the name and regalia.

That reproach cannot be brought against the members of the Society of Professional Auto Engineers. There is a Society of Automotive Engineers, composed not of amateurs as might be hastily inferred, but of engineers engaged in the production of automotive vehicles. But the Society of Professional Auto Engineers is composed of persons who operate automotive vehicles. The coarse unfeeling world has been calling them chauffeurs. "Chauffeur" means the man who heats up, and the Professional Auto Engineers heat up only when you call them chauffeurs. They want to eliminate that disgusting word, not only for themselves but for humbler brethren in similar occupation, who are hereafter to be known as automobile drivers.

Not every automobile driver, it appears, can get into the Society of Professional Auto Engineers. That is confined to "professional operators of automobiles in

private employment." A taxi driver is not a professional automobile engineer. Yet even he is above being stigmatized by the epithet of chauffeur, it seems, and the Society of Professional Auto Engineers wants us all to get into the habit of using the term "automobile driver" for persons who operate taxis and trucks. But for professionals in private employment the term engineer is reserved, thus maintaining the heaven-born distinctions of the caste system on the driver's seat. All that is now needed is a simple terminology to describe the three ranks of passengers; those who own a car driven by a Professional Auto Engineer, those who own and drive their own, and those who own nothing but the price of a taxi ride.

Luckily we have the three terms ready to hand. They come down from old times, with some antique connotations, but their substantial meaning suits the need, nobles, gentry and the common herd.—*New York Times.*

1923 Roster

THE 1923 Roster of the Society will be mailed early in April to those members who ordered copies of it prior to March 15, in accordance with the notice that was sent to all members in December. A small surplus supply has been provided for stock and members who order late will be supplied until the stock has been exhausted, but no reprint of the Roster will be made to supply all those whose orders were received after March 15.

Because of the number of changes of address and company affiliation that are constantly occurring in the roster files of the Society, special care has been taken to obtain the most uptodate information possible and to print the roster as quickly as possible after a specific closing date. Changes in address have been made up to the time of receipt of final page-proofs. Four change-of-address blanks were sent to the entire membership between Oct. 1 and March 15. Approximately 4000 members replied, necessitating 2500 corrections in the files.

To eliminate clerical errors so far as possible and to speed up the work of printing, the writing of copy is eliminated by maintaining a special file of cards for the Roster, which is kept uptodate and furnished to the printer as copy when the Roster is to be printed. This has eliminated 2 months' work of 5 typists and reduced the time consumed in printing the Roster from 4 months to 30 days. This, we believe, gives the members a Roster as nearly uptodate as is physically possible in an organization of the size of the Society.

The book is divided into three main classifications; the alphabetical register, the company list and the geographical register of members. In addition the book contains tables giving the residence of the members by States and the number of members of various grades; charts showing the relative increase in the membership and the distribution of the Society's expenditures; lists of the Society Officers and Councilors, the staff, administrative committees, members of the Standards Committee and its Divisions, Past-Presidents, Society representatives in other organizations, officers of local Sections, Society emblems and publications with prices, and information regarding membership and sections.

In connection with the table showing the geographical distribution of members it is interesting to note that New York State holds the greatest number of members of any single State, although the bulk of the membership is located in the Middle West.

Licensing of Engineers

ACCORDING to documentary information available at the headquarters of the Federated American Engineering Societies, as of Oct. 1, 1922, 23 States of the Union had enacted laws requiring the registration of engineers. The provisions of the various laws differ in some major as well as minor respects, such as the type of engineer and the nature of the engineering work covered, and the time of putting penalties into effect, but all of them are understood to be based upon or the result of a bill promulgated generally by the American Association of Engineers. In the States that require registration of "professional engineers" in general the original and renewal license fees range from $1 to $25.

The following States, in which there are important centers of automotive engineering, have such laws applying to "engineers" and "professional engineers": Indiana, Iowa, Michigan, Minnesota, New Jersey, New York, Pennsylvania and Wisconsin. In addition, there are similar laws in Colorado, North Carolina, Oregon, Tennessee, Virginia, and some other States. The penalties under the various laws have been in effect for some time, except in the case of those of New York and New Jersey, which go into effect next month (May 5) and this month (April 8) respectively. No information is at hand regarding prosecution, litigation or judicial decision under the laws, except an indefinite report as to a suit by an engineer to require a State Board to license him. The stipulated penalties for unlicensed practice range from those for misdemeanor to a $500 fine, or imprisonment, or both.

In general, the professional qualifications for licensing are from 4 to 6-yr. experience, with allowance of from 2 to 4 yr. for education of an accepted grade. Employes of registered engineers are exempt in Colorado, Iowa, New York, Oregon, Pennsylvania and Wisconsin. It is stated that in Michigan the law applies to "consultants"; employes of railroads and other "interstate" corporations are exempt. In some of the States "professional engineering" is defined as the practice of any branch of the profession other than military engineering. The New York law reads:

> A person practices professional engineering * * * who holds himself out as able to do the work that an engineer does in the planning, designing, constructing, inspecting and supervising of engineering work, or appliances involved in public or private projects, or in making investigations for proposed engineering projects.

One of the problems of the administration of the laws is the matter of honoring in one State a certificate of license issued to an engineer in another State, by reciprocal arrangement. In the form of agreement of the Council of State Boards of Engineering Examiners it is stipulated that professional experience shall be considered as beginning when the candidate has entered upon a position in professional engineering work that requires individual thought and responsibility; also, that the applicant shall have had 10 yr. of experience in professional engineering and show that he is qualified to design as well as to direct engineering operations, as evidence of qualification for reciprocal registration, and his experience record shall show progressive advancement in the character of the work performed; in addition, that graduation from an engineering school of recognized standing shall be accepted as the equivalent of 4 yr. of such practice.

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Recent Developments in Aircraft Engines in the Navy

By Lieut. B. G. Leighton[1], U.S.N.

Washington Section Paper *Illustrated with* Photographs and Drawings

That the air-cooled engine in the smaller sizes has definitely arrived and has displaced the water-cooled type in all sizes under 300 hp. in the Naval service is the principal conclusion drawn by the author who also makes the predictions that the air-cooled engine will gradually widen its field of usefulness and displace the water-cooled engine entirely and that the chief hope for bettering aircraft engines lies in perfecting the kind of apparatus that engineers have been accustomed to rather than making any radical departures. These conclusions are reached after an exhaustive discussion of the trend of the successive improvements in engines that have increased the safety, the durability, the dependability and the economy of aircraft. The standard of excellence has been raised from the original 50-hr. test, which consisted of a series of 5-hr. runs, to the present requirement of 300 hr. of continuous running with wide-open throttle at sea-level that represents approximately 600 hr. of normal flying-service and at a speed of 75 m.p.h. would be the equivalent of 45,000 miles of cruising.

The progress made by the Navy Department in reducing the maintenance cost, decreasing the weight per brake horsepower and per cubic inch of piston-displacement and lowering the fuel consumption per brake horsepower by successively redesigning the parts that had failed is outlined, the advances being illustrated by a series of drawings. The possibility of reducing the weight of an engine without sacrificing either strength or durability, as demonstrated in recent designs is emphasized, the text being supplemented by a series of drawings showing the outlines of the engines as compared with the standard Liberty engine and the piston-displacement, the normal power output, the weight per brake horsepower and the piston-displacement per brake horsepower. The Liberty engines have also been undergoing a process of remodeling that has for its object improving their durability and dependability and the weight factor. The predicted performance of the modified types indicates that a marked improvement in all these respects can be expected.

DEVELOPMENT in aircraft construction and operation is limited by two considerations, (*a*) the amount of funds appropriated to the Services by the Federal Government, and (*b*) the effectiveness with which the funds appropriated are expended. I shall attempt to outline the development work that has been done in the particular field of powerplant development with the funds that have been appropriated specifically to the Navy. The scope of the work has been so broad and the details so manifold and varied that time does not permit more than a broad outline of the more important work that has been completed or is in hand. I shall confine myself to the engine itself, and dismiss the subject of accessories, fuel systems, cooling systems and the like, important as they are, with the bare statement that development in these particulars has kept pace with the engines.

In classing this development work as work done "in the Navy" or "by the Navy," I refer to work done under Navy supervision and control, and paid for principally from Naval appropriations. A very great portion indeed of the details of development has actually been executed in private engineering organizations with funds that the Navy has allocated from its appropriations for the particular purpose in view. The Navy's policy has been at all times to handle development projects wherever practicable through the medium of contracts with private engineering organizations, under conditions that assure a reasonable profit to the contractor, to the end that these private engineering organizations may be kept alive and in a healthy condition as the nucleus for the strong well organized commercial aircraft industry that is so vital to the National defense. Without the splendid ingenuity, genius, and resource that have been displayed by the various organizations that have been employed in this work, the results that have been obtained could not have been possible.

It is impracticable to name the various organizations that have been employed in this work, for obvious reasons. Suffice it to say that the Navy has called freely and fully for advice and counsel upon the magnificently organized engineering societies of the country and upon the various Government bureaus and agencies engaged in pertinent lines of work, and has at all times availed itself of the invaluable experience and resources of various private engineering and manufacturing organizations engaged in all manner of engineering work. It has everywhere met with most cordial cooperation and hearty assistance, for which acknowledgment is gratefully made.

Fundamentally, success in aircraft operation, whether it be commercial or military, is largely, one might say almost entirely, dependent upon two vital factors; (*a*) dependability and safety, and (*b*) low operating cost per ton-mile of pay-load carried. Safety and dependability can be had, of course, without low operating cost, but certainly low operating cost cannot be had without safety and dependability. Probably the greatest contributing factor to the present high cost of aircraft operations is the enormous overhead expense incurred by the necessity for frequent and costly repairs and replacements, and by the necessity for constant and most meticulous attention to details. The question of operating cost is perhaps of slightly less moment in military than in commercial operations, but just as high operating costs are today standing in the way of the establishment of the thriving commercial aircraft industry that is so vital to our national defense, so are high operating costs most seriously retarding the full realization to our Army and Navy of the tremendous inherent possibilities in aircraft as a weapon for offense and defense.

[1] In charge of aeronautic engine development, Navy Department, City of Washington.

That our National defense sorely needs a strong self-supporting commercial aircraft industry, goes without saying. The question is, how to create such an industry. And the obvious answer is, let it once be fully demonstrated that aircraft are safe, that they are thoroughly dependable, and that the cost per mile per ton of pay-load carried is comparable to that of other commercial carriers; let these things be clearly demonstrated and there will be no need of worrying about the creation of a commercial aircraft industry; it will create itself.

These factors are properly the first concern of the naval and military aircraft services of our Country, and it is largely in this light that we should view the development work that has been done and is still to be done. Dependability and reasonable durability must come first and always. With thorough dependability comes safety, and a material reduction in maintenance costs. Next in importance to dependability and durability comes the reduction in aircraft weights, because every pound that can be saved in the structure of the aircraft results in a corresponding increase in the pay-load or in the speed and a decrease in the carrying cost.

Former and Present Tests

Generally speaking, an aircraft is only so good as the powerplant that sustains and propels it. Any advance in the performance of the aircraft as a whole can proceed but little faster than the advance in the performance of the powerplant. The two are inseparable. Excellence in performance is purely a comparative factor, and can be visualized only by a reference to some fairly definitely fixed standard of measurement. The standard against which we have in the past measured the excellence of aircraft engines has been the so-called standard 50-hr. test which, stated briefly, requires little more than that an engine shall complete 10 runs each of 5-hr. duration at between 90 and 100 per cent of its rated output without failure in any "major" part, and without "*persistent*" failure in minor parts.

Practically all types of engines in common use today have satisfactorily met the requirements of our 50-hr. test standard, and yet it is a fact that failures of engines and engine accessories have been responsible for more uncompleted flights, forced landings and accidents than all other causes combined. The requirements of the accepted test specifications have been met, but apparently the requirements of actual flight service have *not* been met. It follows, then, that the 50-hr. test as a standard of acceptance must be inadequate. Safety, dependability and economy all demand something far better.

Something over a year ago, the Bureau of Aeronautics of the Navy Department, set up tentatively as a mark to shoot at, a new standard of service acceptability, a test that aimed at demonstrating the entire capability of engines to give continuing dependable service without the necessity for overhaul or other than minor repairs or adjustments for at least as long a period as one might reasonably expect the structure of an airplane to stand up without a thorough going over in normal flight service. The test as originally outlined required three 100-hr. periods of continuous running. Each 100-hr. period comprised 86 hr. at an output corresponding to normal cruising power at 2500-ft. altitude and 14 hr. at wide-open throttle at sea level, to simulate the conditions that obtain in the take-off and the initial climb. This was a long step ahead of the old standard 50-hr. test requirement, and it must be confessed that when we first set up the new standard we were actuated very much more by a determined hope than by confident expectancy. A year's intensive work on a number of types of engine has fully convinced us, however, that this measure of excellence is capable of being fully realized in all classes of engine, without in any way increasing the weight, and we have recently raised the standard to 300 hr. of continuous wide-open throttle running at sea level.

It should be fully realized that wide-open throttle running at sea level taxes an engine far more than does the kind of running that it gets in the hands of an experienced pilot in normal flight service. Actual comparisons made between the conditions noted in identical engines after full-throttle sea-level running and after normal flight operation indicate clearly that the life of an engine in normal flying service is at least double the life of the same engine under full-throttle sea-level running. On this basis, which our experience indicates to be entirely safe, a 300-hr. wide-open throttle test at sea level is the equivalent of at least 600 hr. of operation in normal flying service. At an average cruising speed of 75 m.p.h., this represents some 45,000 miles of cruising. Few airplanes have yet been built whose structures will stand up for this amount of cruising without very complete and extensive overhaul, if at all. I mention these things to indicate that the goal we are aiming at is far above the present general measure of acceptability.

Progress Made in Development

As an example of the type of work that has been done, I shall cite several specific instances. An engine of the model that is being installed in our first rigid airship, the Packard 1A-1551 shown in Fig. 1, has already completed 300 hr. of practically continuous running, developing the maximum output that it will be called upon to develop in flight service. No repairs or refitting of the parts were made throughout the entire test and at the end of the test a careful inspection proved the engine to be still in excellent running condition and in need of no repairs or adjustments. As an indication of the excellent valve conditions that obtained, the average fuel-consumption of this engine for the whole 300 hr. of running was slightly less than 0.44 lb. per b. hp-hr. In fairness to other models of aircraft engines, it should be pointed out that this engine was especially designed for airship service and is very much heavier than the engines used in other classes of service.

In the lighter types of engine that are more particularly adaptable to heavier-than-air service, we have completed a 300-hr. test in three 100-hr. periods with the Aeromarine U-8-D, an eight-cylinder V-type water-cooled engine. During this test the engine was run at part throttle at 1800 r.p.m. developing an output equal to its normal cruising power at a 2500-ft. altitude for a total of 258 hr. and at wide-open throttle at sea level for 42 hr. At the end of the 292nd hr. of the test, a break occurred in the crankshaft, which required the installation of a new shaft to complete the run. This break was serious, of course, but was of such a nature that the cause was very evident and the remedy comparatively simple. Aside from this failure, and a slight retouching of part of the intake-valves at the end of the first 100 hr., no adjustments or repairs were made to the engine throughout the test. At the end of the test the power output of the engine was slightly greater than at the beginning, the valves and their seats, the bearings, the gears and in fact all parts were in excellent condition and in need of no repairs or refitting. This was an extremely gratifying performance from the standpoint of durability and a distinct encouragement, but the engine as tested compared unfavorably in weight

per horsepower and in installation dimensions with another engine of approximately the same power that had been in wide service use.[2] We accordingly set about having changes made in the design not only to decrease its weight materially, but at the same time to increase its output materially, keeping still the same excellent durability characteristics. The redesign, which is designated as the U-873, was completed and subjected to preliminary tests at the increased output. Certain difficulties were encountered that entailed a slight further redesign in certain parts to maintain the all-around durability characteristics desired. The engine is now finally completed, has satisfactorily undergone its preliminary trials and is about to be subjected to its final endurance test, comprising 300 hr. of continuous full-power run-

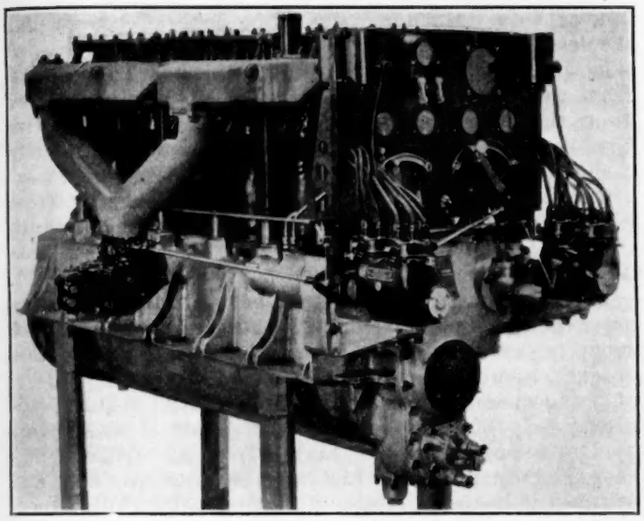

FIG. 1—ENGINE DEVELOPED BY THE PACKARD MOTOR CAR CO. FOR INSTALLATION IN THE NAVY'S FIRST RIGID AIRSHIP

ning. All indications are that this test will be satisfactorily completed. The original model of this engine, the U-8-D, weighed 575 lb. and developed 225 b. hp. at 1800 r.p.m. The modified engine now under test, the U-873, weighs 520 lb. and develops 260 b. hp. at 1800 r.p.m.

Another, and materially lighter model, the Wright Model E-2, having approximately the same general characteristics as the U-8-D was submitted to the same test. This model, which is a development of the small Hispano-Suiza, has been used extensively in our service for advanced training airplanes with very good results by comparison with other engines previously in general use. Our records show that its flying life between overhauls averages 101 hr., as against 72 hr. for the Liberty engine, It had repeatedly been subjected to standard 50-hr. tests and was thought to be an exceptionally durable type, but when we commenced long-duration testing unexpected shortcomings were uncovered, principally in the connecting-rod bearings, the valves and the valve-seats, all of which went bad before the first 100 hr. had been completed. The subsequent development work on this engine is particularly interesting because the results obtained have so completely justified our adoption of the 300-hr. test standard in place of the old 50-hr. standard.

Figs. 2 and 3 show the progress that has been made. Referring to Fig. 2 the graph marked 1, is a graph of the first attempt at a 300-hr. run. Note that in the 14-hr. full-throttle running at the end of the period the

[2] For a specific example of the importance of low weights, see the Appendix.

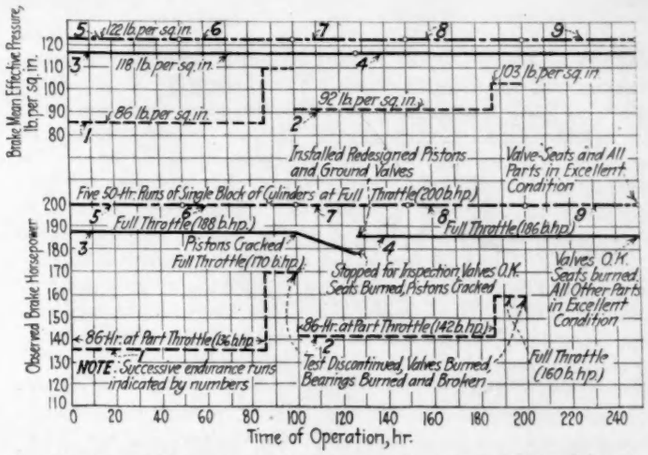
Brake Mean Effective Pressure, lb. per sq. in.
Observed Brake Horsepower
Time of Operation, hr.
122 lb. per sq. in.
118 lb. per sq. in.
86 lb. per sq. in.
92 lb. per sq. in.
103 lb. per sq. in.
Installed Redesigned Pistons and Ground Valves
Valve Seats and All Parts in Excellent Condition
Five 50-Hr. Runs of Single Block of Cylinders at Full Throttle (200 b.hp.)
Full Throttle (188 b.hp.)
Pistons Cracked Full Throttle (170 b.hp.)
Stopped for Inspection, Valves O.K. Seats Burned, Pistons Cracked
Full Throttle (186 b.hp.)
Valves O.K. Seats burned All Other Parts in Excellent Condition
86-Hr. at Part Throttle (156 b.hp.)
86-Hr. at Part Throttle (142 b.hp.)
NOTE: Successive endurance runs indicated by numbers
Test Discontinued, Valves Burned, Bearings Burned and Broken
Full Throttle (160 b.hp.)

FIG. 2—CHART SHOWING THE RESULTS OF PROGRESSIVE DEVELOPMENT ON ONE TYPE OF ENGINE DURING 1 YR.

power output was considerably below the normal rated power of this model, 180 b. hp. at 1800 r.p.m. This condition was brought about by the poor valve conditions. After this run new connecting-rod bearings and valves of the original design were fitted, the valve-seats were reamed out and the valves readjusted, and a second attempt was made as a check on the first, with the result shown in the graph numbered 2. After some investigation and experimentation, new valves and bearings were developed and were fitted in a new engine of the same model. This engine was then set up and subjected to a practically non-stop run of 125 hr. at wide-open throttle as shown in the graph marked 3. An examination at the end of this test showed no evidence of bearing failure and that the valve burning had been corrected completely, but that the valve-seats were seriously eroded. The valves were reseated and adjusted and new pistons

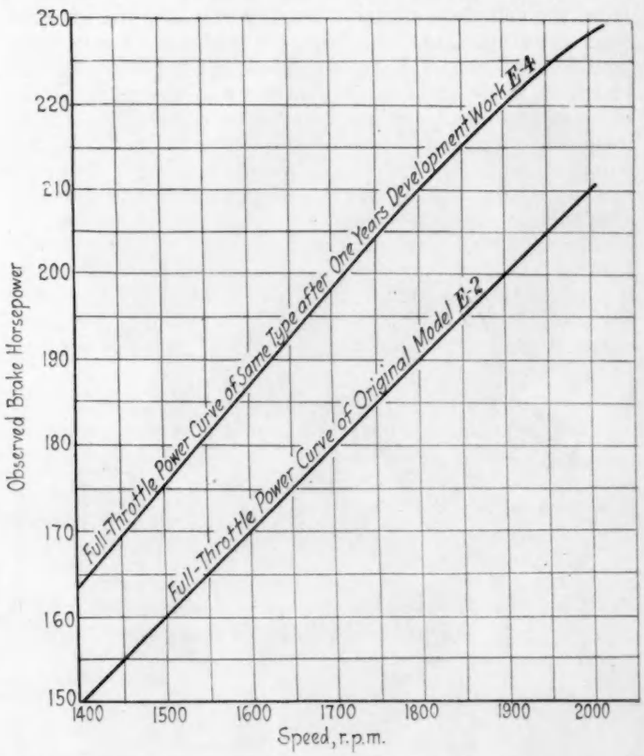
Observed Brake Horsepower
Speed, r.p.m.
Full-Throttle Power Curve of Same Type after One Years Development Work E-4
Full-Throttle Power Curve of Original Model E-2

FIG. 3—COMPARISON OF THE POWER DEVELOPED BY THE E-2 AND E-4 ENGINES

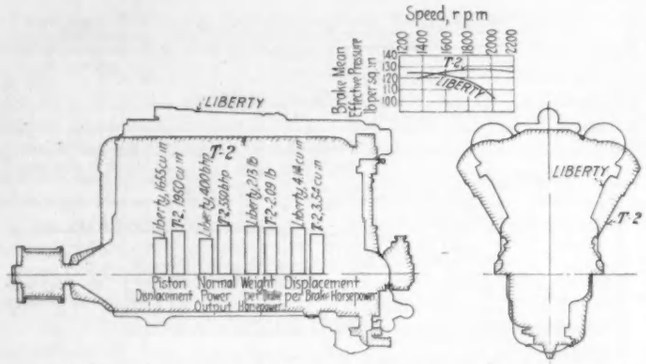

FIG. 4—COMPARISON OF THE STANDARD LIBERTY AND THE WRIGHT MODEL T-2 ENGINES

of a modified design installed. No other parts were repaired, replaced or refitted. This same engine was then submitted to a second continuous run of 125 hr. at wide-open throttle as shown in the graph numbered 4. At the end of this run the modified pistons were in excellent condition. The valve-seats were again found to be badly eroded, but the valves were still in excellent condition. A careful inspection disclosed no evidence of deterioration or serious wear in other parts. Further testing of this engine was discontinued and it was laid aside until means could be found to overcome the valve-seat difficulties. An entirely new design of cylinder-block was laid out and one block built for test. At the same time changes were made in the cam contour to better the volumetric efficiency and increase the output. A single block of this new design has recently been subjected to five consecutive 50-hr. non-stop runs at full throttle. The graphs numbered from 5 to 9 inclusive indicate the results of these runs. In preparing these latter graphs the output of the single block has been doubled to represent the output that is to be expected from the complete engine. During this 250 hr. of wide-open running, there has been no evidence of any valve trouble, the valves have not been ground nor any adjustment made and both the valves and the seats appear to be in practically as good condition as when originally installed. Two of these new cylinder-blocks with the modified cams have been substituted for the old-style blocks on the same engine that completed the previous 250-hr. test and this engine is now being set-up for further endurance running at wide-open throttle. Aside from the new cylinder-blocks and the cams, this engine is in exactly the same condition as at the end of the previous 250-hr. test; no adjustments, repairs or replacements in other parts have been made. All of the changes mentioned above are being incorporated in new engines under construction, which are known as Model E-4. In Fig. 3 is shown a power curve of the original E-2 and of the modified engine as determined by actual test of assembled engines. While a full 300-hr. test at continuous wide-open throttle has not yet been completed with this engine, the running that *has* been done justifies the prediction that this engine as modified is easily capable of withstanding such a test.

Work of a similar nature to that outlined above has been in progress in all classes of engine for all types of service with very similar results. Invariably, the efforts that have been made have resulted in a marked increase in the durability, and practically without exception changes in the design have at the same time resulted either in a decrease in the weight, an increase in the output, or both. Much remains to be done, of course, but the lessons learned from the development work in one type are usually more or less applicable to all types, and from the tests that have been completed thus far and from those that are now in course of completion, we have become fully convinced that it is a question of only a short time until we shall have a complete line of engines for all types of service operations ranging from 60 to 700 hp., some air-cooled, others water-cooled, which will be capable of withstanding at least 300 hr. of continuous full-throttle running without failure in any part.

The costs involved in overhauling aircraft engines are not generally appreciated. The records of our service show that the standard Liberty engine, a 50-hr. test product, requires a complete overhaul after every 72 hr. of flying operation. Averages show that it requires approximately 300 man-hr. of direct labor at each overhaul to remove a Liberty engine from an airplane, disassemble, clean, repair and refit, reassemble, test and reinstall it in the airplane. This does not include supervision or transportation to and from the shop. In other words, for every hour that the engine flies, 4.2 man-hr. of direct labor must be paid for within the walls of the overhaul shop. Skilled labor is required for this work. I believe that $1.50 per man-hr. is a very conservative figure for the cost of such labor plus overhead, which gives a cost in overhaul labor alone of $6.30 per flying-hr. of the engine. At a cruising speed of 75 m.p.h., this represents an overhaul labor cost of 8.4 cents per mile for a single-Liberty-engine airplane. It does not include the cost of any replacement parts required in connection with the overhaul. These oftentimes reach a value up to 25 per cent of the total cost of a new engine. It does not include the cost of the operating and the field maintenance crews and equipment. The overhaul cost of operating an engine is inversely proportional to

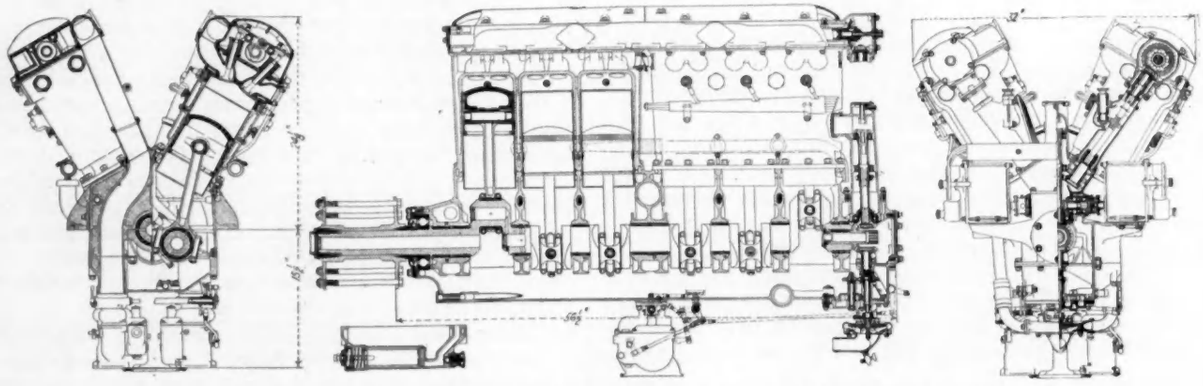

FIG. 5—TRANSVERSE AND LATERAL SECTIONS OF THE WRIGHT T-2 AIRCRAFT ENGINE

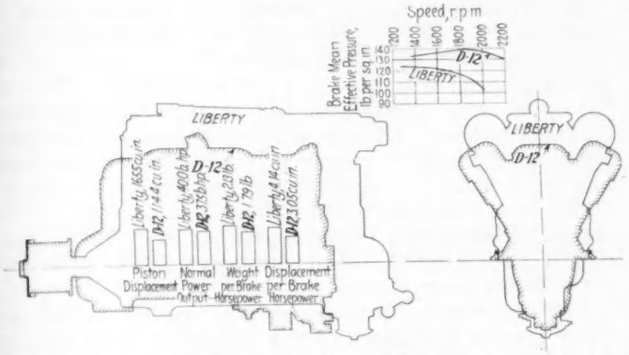

FIG. 6—COMPARISON OF THE STANDARD LIBERTY AND THE CURTISS D-12 ENGINES

the durability of the engine. As I have previously indicated, the 300-hr. wide-open throttle test that we are now coming to adopt as standard is probably the equivalent of not less than 600 hr. of normal flying operation. It requires only a little elementary arithmetic for one to appreciate the importance of this work.

The work that has been done has most forcibly demonstrated two extremely important things, (*a*) that we may confidently predict for the immediate future a degree of dependability and durability in aircraft engines that will at least equal that of the aircraft structure itself, which means that the frequent removal of engines from aircraft for overhaul is not necessary and that the quantity of spare engines and replacement parts can be enormously reduced, and (*b*) that to realize this degree of dependability it is not necessary that the weight per horsepower developed be at all increased over the weights that are present in the ordinary engines of today.

REDUCTION IN WEIGHT

Contrary to a rather widely accepted belief, the features that result in the greater decreases in the weight are at the same time features that inherently tend to increase rather than decrease the factors of safety in vital engine parts. To use a familiar example, a 12-cylinder V-type engine can inherently be made more durable than a 12-cylinder in-line engine of the same weight and power for the reason that the backbone of the engine, the crankcase and the crankshaft, are, due to their shorter lengths, enormously stiffer. Long crankshafts and crankcases are inherently heavy, flexible and weak; short crankshafts and cases are inherently light, stiff and rugged. A multiplicity of parts is, within reasonable limits, an enemy to ruggedness and dependability, and in a large measure at least is incompatible with light weight. Within limits, it requires less weight of metal to enclose a given cylinder volume in a few cylinders of large bore than in a large number of cylinders of small bore, After all, and again within limits, it is the total piston displacement that largely determines the limiting possible output of an engine, not the number of cylinders. The more recent engine designs that have been developed for our service have all been drawn up with these principles in view. Figs. 4 to 9 illustrate the results of this trend in design. Fig. 4 is a comparison of an engine that has been recently developed, the Wright Model T-2 that has 1950-cu. in. piston displacement, a normal output of 550 b. hp. and weighs 1150 lb., with the standard Liberty engine. No weight has been spared in the design of the stressed parts. As a matter of fact, its weight per cubic inch of piston displacement is considerably greater than in the Liberty engine for this reason. But it has on test fully demonstrated its ability to stand up to a 550-hp. output immeasurably better than the standard Liberty stands up to a 400-hp. output, and the weight per effective horsepower output has consequently not been increased. Transverse and lateral sectional views of this engine, which has been completely described in the technical press,[3] are presented in Fig. 5.

Fig. 6 is an outline of a smaller 12-cylinder engine, the Curtiss Model D-12, that is especially adaptable to pursuit work, which has been perfected, during the past year, and which is now being used rather widely in newer types of aircraft. This engine, the propeller end of which is illustrated in Fig. 7, has a total piston displacement of 1145 cu. in., weighs 670 lb., and develops 375 b. hp. at 1800 r.p.m. An engine of this type has recently completed a 100-hr. endurance test without failures or serious deterioration in any parts, and is now being subjected to further testing at full throttle. Previous to the 100-hr. test, this same engine, an illustrated description of which has been published in at least one trade journal,[4] had completed something over 100 hr. of preliminary test running during which certain minor changes in the design were incorporated. So far as the highly stressed parts are concerned, however, no evidence of weaknesses have been uncovered in more than 200 hr. of test running at or above three-quarters power.

Fig. 8 is an outline of another experimental type now under construction. This engine is barely out of the design state at present and for this reason I should hesitate to mention it were it not that it illustrates so well the possibilities in the reduction of weight per unit of power through economy in the crankcase and the crankshaft lengths, rather than by a reduction of the sections in the stressed parts. By an ingenious and somewhat

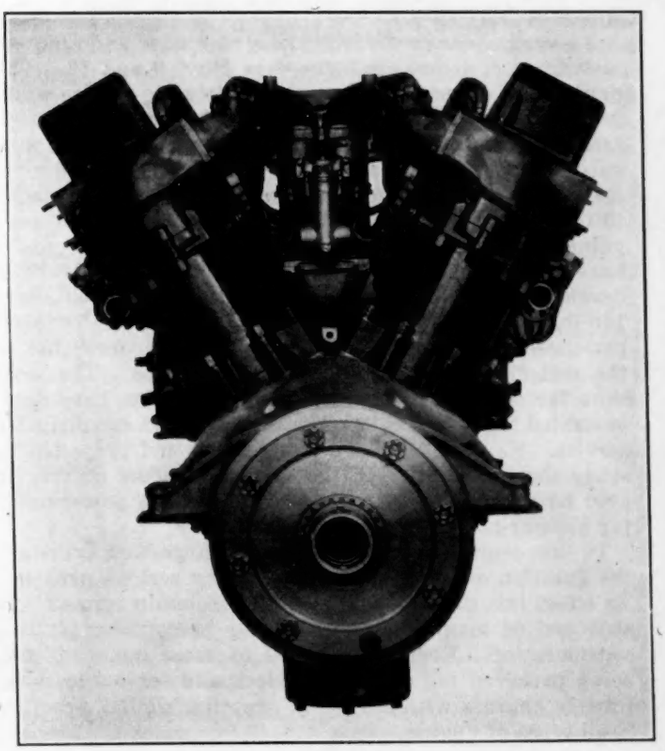

FIG. 7—THE PROPELLER END OF THE CURTISS D-12 ENGINE THAT HAS BEEN DEVELOPED FOR PURSUIT WORK

[3] See *Automotive Industries*, July 13, 1922, p. 57.
[4] See *Aviation*, Oct. 16, 1922, p. 496.

unusual cylinder arrangement and construction, it has been possible to obtain a total piston-displacement of 2450 cu. in. in the extremely small over-all dimensions shown. The weight will be 1150 lb. It has been designed for an assumed output of 775 hp. at 1800 r.p.m. but for purposes of preliminary trials will be rated at 625 hp. at 1650 r.p.m. Its weight per rated horsepower will be 1.80 lb. and on the designed 775-hp. basis its weight will be 1.55 lb. per hp. This engine is not yet completed and hence no test data can be given, but by virtue of the extreme compactness of the design and by a careful study of the stress distribution it has been possible to provide unusually high factors of safety in all the highly stressed parts and still keep the over-all weights extremely low. By virtue of these high factors of safety, the dependability and the durability should be very excellent indeed. Other new experimental models that promise comparable weights per horsepower with excellent durability characteristics are now under construction and are expected to be ready for running tests in the near future.

The practicability of using much larger cylinder-bores than are commonly used in aircraft engines has been under the most careful investigation. A six-cylinder vertical in-line engine that has cylinders of 7-in. bore and 8-in. stroke has been built and recently tested. A complete description of this engine, the Wright Model D-1,

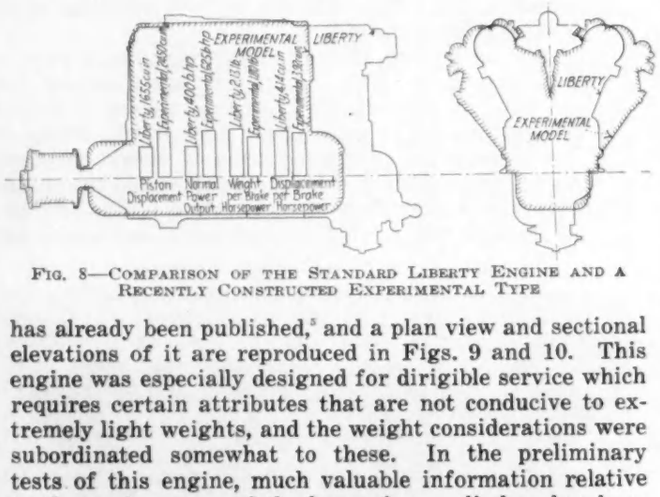

FIG. 8—COMPARISON OF THE STANDARD LIBERTY ENGINE AND A RECENTLY CONSTRUCTED EXPERIMENTAL TYPE

has already been published,[5] and a plan view and sectional elevations of it are reproduced in Figs. 9 and 10. This engine was especially designed for dirigible service which requires certain attributes that are not conducive to extremely light weights, and the weight considerations were subordinated somewhat to these. In the preliminary tests of this engine, much valuable information relative to the performance of the larger-bore cylinders has been gained. Special high-performance runs of a test cylinder have been conducted at a compression-ratio of 6.5 to 1, developing a brake mean effective pressure of well above 140 lb. per sq. in. at 1400 r.p.m. No trouble has been experienced in cooling the pistons or the cylinders either in the test cylinder or in the complete engine. The tests thus far conducted with the complete engine have demonstrated the entire suitability of the design for dirigible service. Further tests are being made and projected to study the possibilities in the use of cylinders of this or even larger sizes in the construction of larger power units for heavier-than-aircraft service.

In this connection, with the use of large-bore cylinders the question of inertia forces is a very serious problem. To offset this difficulty, the use of duralumin connecting-rods and of magnesium pistons has been under serious consideration. Rods and pistons of these materials are being procured for exhaustive block and service tests in Liberty engines with a view to adopting similar practice in all types of engine.

[5] See *Automotive Industries*, April 20, 1922, p. 852.

In all the more recent designs, the possibilities of increasing the rotative speeds and the brake mean effective pressures have been kept constantly in mind and the newer designs have been laid out accordingly. That the factors of safety provided are adequate to withstand overloading has been well demonstrated in special high-power running of the more recent designs. The engine shown in Figs. 4 and 5 has been run for hours continuously at a 20-per cent overload without failure in any part. The engine illustrated in Figs. 6 and 7 has been flown repeatedly in racing service at an output of 450 b.hp. at 2300 r.p.m. without any evidence of failure.

The question of realizing higher specific power and lower specific fuel-consumption through the use of high compression-ratios has been investigated thoroughly. We are indebted to the Bureau of Standards for much valuable research in this line, not the least of which has been a study in collaboration with the Bureau of Mines, of the sources of supply for various anti-knock fuels in the Country. Much of the work that has been done in this connection by the Bureau of Standards has already been presented in a paper[6] read by S. W. Sparrow at the recent Annual Meeting of the Society entitled Testing Fuels for High-Compression Engines. As the result of this work, coupled with a considerable amount of corroborative block and flight testing that we have done with various service types of engine, we have become thoroughly convinced of the entire practicability of using in general service considerably higher compression-ratios than we are now using. The chief problem to be solved is, of course, the procurement of a fuel that will not only eliminate detonation without interfering with proper engine operation in cold weather, and without attacking the materials of the engine, but that will also be readily available for general distribution in large quantities at a reasonable cost. For example, benzol has a tendency to solidify at cold temperatures. Anhydrous alcohol appears to fulfill the requirements very satisfactorily, and we are now after an extensive preliminary investigation, proceeding with final-service tests by conducting all flight operations at three of our air stations, with a blend containing 30 parts of alcohol and 70 parts of gasoline.

The use of higher engine speeds for increasing the output without any increase in the weight is very attractive but is only of real advantage if light weight and thoroughly dependable reduction gears are available. This is one of the most difficult problems that we have had to face. It is a relatively simple matter to make durable gears, but far from simple to make *light* durable gears that will stand up as long as the rest of the powerplant. This problem appears now, after more than 4 years of continuous study and experiment, to have been solved pretty well. One very important development has been the interposing between the crankshaft and the gears of spring couplings that iron out the torsional vibrations and relieve the gear teeth of the immense fatigue stresses imposed with the ordinary rigid connections. We are now proceeding, with confidence, to the construction of dependable and durable gears that have an over-all weight of 0.25 lb. per hp. absorbed, or less.

The Liberty engine, owing to the fact that so many engines of this type are already on hand, deserves more than passing attention. It has been apparent for some time past that the standard Liberty engine has rapidly been falling behind the procession. It has neither the durability, the dependability nor the weight factor to compete successfully with the more modern types. Its life in normal service, as I have mentioned before, is but 72 hr. between overhauls and it requires constant and

[6] See THE JOURNAL, January, 1923, p. 11.

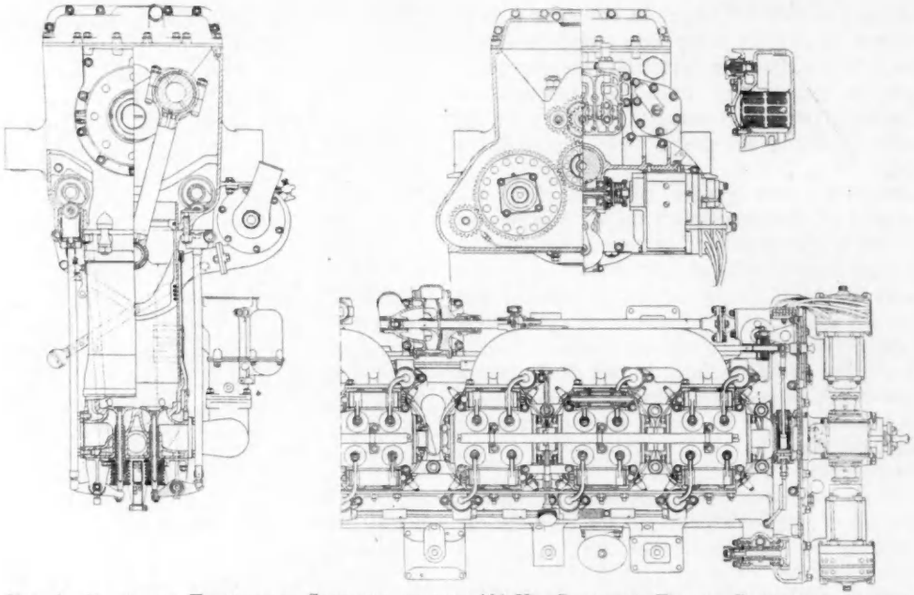

FIG. 9—PLAN AND TRANSVERSE SECTIONS OF THE 400-HP. DIRIGIBLE ENGINE DEVELOPED BY THE WRIGHT AERONAUTICAL CORPORATION FOR THE NAVY DEPARTMENT

most meticulous attention at all times. Forced landings due to all manner of minor failures, and occasionally due to major failures, are relatively frequent and not infrequently result in the complete loss of aircraft. We can ill afford to predicate our National defense upon aircraft equipped with this engine, when such aircraft must be called upon to meet on equal terms aircraft equipped with more modern types. Yet we can ill afford to discard the large supply of these engines that still remains in store, bought and paid for, and purchase from present appropriations new engines to replace them.

A careful study of the failures that occur in Liberty engines in service indicates that the weakness of the engine lies primarily in its lack of rigidity, in the manifolding and in the valve-actuating mechanism. Probably the most annoying source of trouble lies in the frequent occurrences of water-jacket leakages in flight. This trouble cannot, apparently, be corrected short of a complete redesign of the cylinders. This is at present being done, experimentally. To kill three birds with one stone, the redesign of the cylinders has taken the form of a six-cylinder aluminum cylinder-block, with a complete new cam-actuating mechanism and an intake-manifolding that follow very closely the cylinder, valve and manifolding design of the more modern types. The use of the block construction enormously stiffens the engine and should, in a large measure at least, eliminate the troubles that have resulted from this lack of rigidity. At the same time the jacket failures are eliminated, while the new valve-mechanism and the manifolds result in a materially improved volumetric efficiency. Other minor modifications have already been made, or are being made, in standard engines in service to correct timing-gear breakages, generator failures, connecting-rod bearing difficulties, piston burning and the like.

The first experimentally modified engine is practically

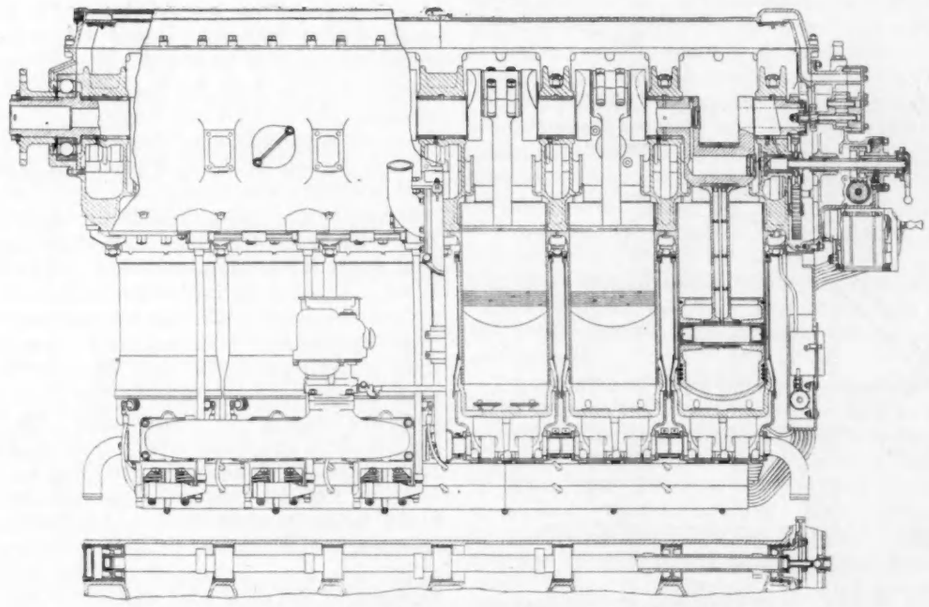

FIG. 10—LONGITUDINAL SECTION OF THE WRIGHT DIRIGIBLE ENGINE

completed and trials of it will be begun in the near future. It is too early as yet to predict with assurance its entire suitability for service use, but the fact that the new parts installed incorporate practically identical features to those now in common use with superior results in the more recent models, should assure a very marked improvement indeed.

In Fig. 11 are given two graphs showing first the present power output of the standard Liberty engine and second the predicted performance of the modified engine, based upon the actual test results obtained with a similar cylinder, valve and manifold construction in other types of engine. Particular attention is drawn to the relatively low brake mean-effective pressure values realized in the standard Liberty engine and especially to the sharp break in the brake mean-effective pressure curve at about 1650 r.p.m. It is this characteristic as much as the frequent cylinder-jacket failures that has led us to a complete redesign of the upper works of the engine.

In this modification we have cut deep, it must be admitted, but after a most careful study and the continuous testing of a number of alternative courses that suggested themselves, we have become convinced that there is no other way. We have been greatly restricted in this work by the fact that modified parts must always be applicable to the standard Liberty crankcase, crankshaft, connecting-rods, pistons and accessories. There is no doubt that the power output shown in Fig. 11 will be realized, nor is there any doubt that the engine as modified will be measurably more durable and dependable than the standard Liberty. The only question is, how *much* more dependable and durable it will be. This is a question that can be answered only by the actual running tests that are about to be begun.

The Air-Cooled versus the Water-Cooled Engine.

I have been rather hesitant about entering such controversial ground as a discussion of the relative merits of the air-cooled and the water-cooled engine, but the work

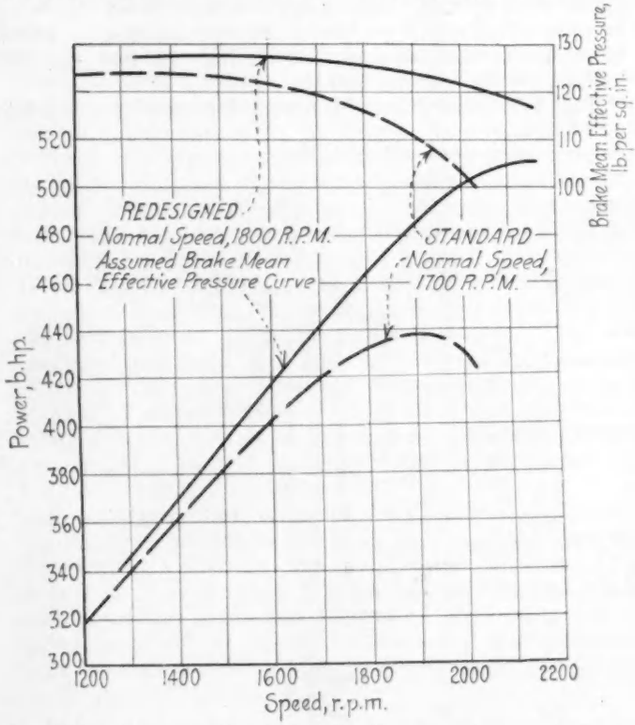

Fig. 11—Comparison of the Power Developed by the Standard and the Redesigned Liberty Engine

that we have been doing during the past 2 years has brought so much definite information to light that the subject cannot well be passed over. If we assume equal durability, flexibility and fuel economy, I believe that every one must agree that the air-cooled engine must have a distinct advantage over the water-cooled engine for aircraft service, owing to the elimination of the weight and the complications imposed by radiators, water and piping. The chief contention between the air-cooled and the water-cooled proponents appears to be one of whether the air-cooled engine can be made to equal the water-cooled engine in these three characteristics. It has also been contended by the water-cooled proponents that the air-cooled engine must, due to its relatively large frontal area, have a much higher head-resistance factor than has the water-cooled engine. These questions have been largely based on surmise. Little really definite comparative information has been at hand, for the simple reason that until very recently there have been no air-cooled engines of any considerable output available in this Country for actual comparative flight tests.

Something over 2 years ago, we began in real earnest an intensive development and testing program to determine definite answers to these questions. The first requirement was of course to get, for flight service, an air-cooled engine that would have an output comparable to more commonly used water-cooled engines. Five engines of an experimental type, the Lawrance Model J, a conventional nine-cylinder radial, having a rated output of 200 hp. at 1800 r.p.m., were contracted for, for development purposes.

The first of these engines was completed about 18 months ago, was placed on a test-stand and test running begun mostly at wide-open throttle. The thermal characteristics of the engines as originally designed proved to be entirely sound and to require no modification. A number of mechanical troubles developed, however, as the tests continued, involving changes in the crankcase design, the crankshaft and main-bearing design, the cylinder securing, the valve-springs, the cams, the accessory drives, the propeller-hub and all manner of minor details. Parallel with these block tests, sample engines have been in actual flight service for a period of nearly a year. The same engine has been flown in weather ranging from the hottest days of summer to the lowest temperature yet encountered this winter, 16 deg. fahr., from sea level to 20,000 ft., in dry weather and rain, in parallel service with the best water-cooled engines of comparable power that we know of today. Troubles have been encountered to be sure, *many* troubles, but they have almost invariably been troubles of a mechanical nature, and without exception means have been found for overcoming them. Not one instance of trouble of any nature has been found that has been at all inherent in the fact that the engine was air-cooled rather than water-cooled. We have found no indication in any of our tests during more than 2 years of constant running of engines of this type that the air-cooled engine as such is less efficient, less flexible, less powerful, less dependable, less durable or more sensitive to changes in the altitude or in the temperature than is the water-cooled engine. It is certainly lighter than the water-cooled engine with its radiator, it requires less preliminary running to warm up in cold weather and less attention on the part of the pilot in flight and its installation is distinctly simpler and cheaper.

To obtain an indication of the relative aerodynamic features of the air-cooled and water-cooled types, we have built for comparative flight tests three types of airplane

that are exactly alike in all respects except for the power-plant installations. One of these types has the air-cooled engine installed, the other two types have two different models of water-cooled engines. Two of these airplanes, one equipped with the Wright Model E-2 water-cooled engine and the other with the Lawrance Model J-1 air-cooled engine, were entered in the Detroit races this year. Unfortunately, the water-cooled type did not finish due to a broken propeller-tip that forced her out of the race. But from comparative flight trials prior to the race and from recorded times for the early laps of the race, it is pretty conclusively established that the two machines, using identical propellers turning at the same number of revolutions per minute, were exactly equal in speed. The power output of the E-2 engine was brought up to that of the J-1 engine by installing in the E-2 special high-lift cams and special pistons to give a compression-ratio of 6.5 to 1. The J-1 engine was in all respects standard.

I regret that our testing program in this regard is not yet completed, and that complete quantitative data are not, therefore, yet available. All information as yet available, however, appears to confirm the results noted during the Detroit races.

The wide investigation that we have pursued during these past 2 years appears to have established beyond the range of surmise the following characteristics for the air-cooled engine of smaller powers up to, say, 300 hp., as compared with the best existing types of water-cooled engines of comparable power.

(1) There is nothing inherent in the air-cooled engine that renders it less durable or dependable as a mechanism than is the water-cooled engine

(2) As regards thermal characteristics, the air-cooled engine is at least the equal of the water-cooled engine. Block and flight tests over a period of many months have demonstrated a specific power and specific fuel-consumption that is the equal of the best water-cooled engines of comparable power that we know of

(3) The air-cooled engine is not unduly sensitive to wide changes in the atmospheric temperatures in flight service

(4) The head-resistance of the radial air-cooled engine of the largest size that we have had in flight, 43-in. diameter overall, is not greater than that of the water-cooled engine of the same power plus the necessary radiator

(5) The air-cooled engine is much more quickly warmed up and made ready for flight in cold weather than is the water-cooled engine and will withstand long glides and dives at a high altitude without interfering with its operation

(6) The air-cooled engine requires less attention on the part of the pilot than does the water-cooled engine

(7) The weight of the air-cooled engine is unquestionably inherently less than that of the best water-cooled engine with its radiator and water. In this connection, I have prepared Fig. 12 to show at a glance a comparison between the dimensions and general characteristics of two actual types now in general use in our service, the Lawrance Model J-1, air-cooled, and the Wright Model E-4, water-cooled. The data shown in this figure represent actual test data for the most recent models of each type. The weight data for each type are based upon the *dry* engine; the water and the radiator of the water-cooled engine are not included. This represents an additional handicap in favor of the air-cooled type of approximately 0.6 lb. per hp.

The conclusions to be drawn from these facts, and they

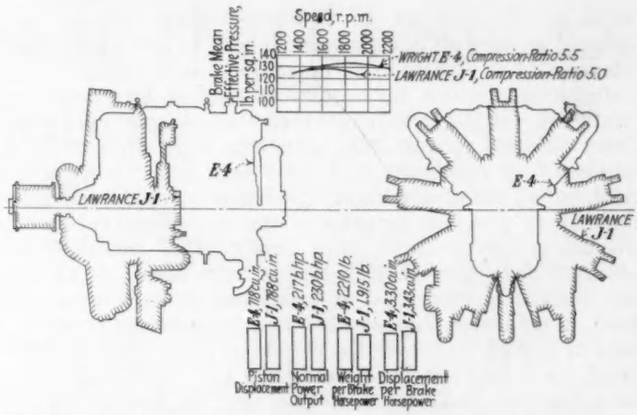

FIG. 12—COMPARISON OF THE WRIGHT E-4 AND THE LAWRANCE J-1 ENGINES

now are fully demonstrated facts, not surmise, are perfectly obvious.

What are the possibilities in air-cooled engines of larger powers remains to be determined. The engineering division of the Army Air Service has in its excellent research at McCook Field demonstrated the entire practicability of constructing air-cooled cylinders of large displacement that have thermodynamic characteristics equal to the best water-cooled construction. It remains only to solve the relatively simple mechanical details of combining such cylinders into a larger-power engine without exceeding reasonable frontal dimensions. How large diameters are practicable before the head-resistance factor of the conventional radial engine becomes an offset to the other inherent advantages of the air-cooled type is a question that can be decided only by actual flight trials which must naturally wait upon the development of larger air-cooled engines that are now being projected. The question of frontal dimensions is largely a question of mechanical arrangement. We are now investigating valve arrangements that will permit a very material reduction in radial-engine diameters through the elimination of the top hamper now used in the conventional overhead poppet-valve cylinder designs. A highly experimental engine is under construction that entirely eliminates the overhead valve-gear, there being nothing at all above the cooling fins of the cylinder-head proper. It is too early to predict the outcome of this project, but the advantages to be gained not only in the way of head-resistance, but in over-all weight as well, are self-evident.

The air-cooled engine, at any rate in the smaller sizes, has definitely arrived, and is in our service definitely displacing the water-cooled engine in all sizes up to 300 hp. No new types of water-cooled engine in these powers are contemplated. What the future is for air-cooled engines of larger powers we are not yet prepared to say definitely, but the prediction is ventured that just as the air-cooled engine is now displacing the water-cooled types in the smaller powers, so will it extend its field progressively to the larger powers and displace the water-cooled engines in this field.

I have outlined only the more important work that we have been doing along more or less conventional lines, namely in the four-stroke Otto cycle reciprocating engine. These are the things of the present and the immediate future. That we have not confined ourselves to convention alone, you may be sure. Many other lines have been or are being investigated. I have refrained from mentioning investigations that we have been making along other lines, for example, in high-speed solid-injection

auto-ignition engines, in two-stroke cycle engines and others, because all of this work is still in its preliminary stages and is still too full of conjecture to warrant any definite predictions for results as applied to actual aircraft use. It is not to be doubted that radical departures from present conventional practices will, soon or late, gradually or suddenly, find their way into the aviation field, but as yet no new departure has presented itself that appears to give any promise in the immediate future of displacing the present more conventional practices in common use. Our chief hope for betterment, so far as the present is concerned at least, lies in perfecting the kind of apparatus that we have been accustomed to using. And in looking back over the results of the recent development work that has been done with the funds that have been made available to us, we feel that the funds have on the whole been spent to good advantage, that the safety, the dependability and the operating cost of aircraft have been very materially improved, and that the strong commercial aircraft industry that the National defense so sorely needs is thereby much closer to realization than it has ever been before.

APPENDIX

Influence of Powerplant Weight on Transportation Costs

One often hears the statement that the requirements for commercial aviation are very different from those for military aviation, that for commercial aviation one can afford to use considerably heavier engine types than are at present in common use for military aircraft. A rather careful study of the influence of powerplant weight on the amount of pay-load that can be carried throws some interesting light on this subject. I have taken as the basis for comparison the performance of a type of aircraft that has recently been developed, and that has an unusually high carrying load per horsepower by comparison with existing types of aircraft.

The total gross weight of the machine as built is 7175 lb. The engine used is a standard Liberty developing 400 b. hp., which gives a power loading of 17.9 lb. per b. hp., a very satisfactory figure. With a cruising radius of 500 miles this plane as built can carry a pay-load of 1010 lb.

The powerplant weights, exclusive of fuel, are as follows:

	Lb.
Dry Weight of Liberty Engine	872
Engine Accessories	58
Hand Starting System	17
Propeller	58
Dry Weight of Cooling System	132
Cooling Water	113
Dry Weight of Oil System	33
Dry Weight of Fuel System	184
Engine Controls	15
Total Powerplant Weight	1,462

As a basis of comparison, I have taken a purely hypothetical assumption that an air-cooled engine that will deliver 400 hp. and that will weigh 600 lb. dry is available to replace the standard Liberty engine. I believe that such an engine is capable of being built. With such an engine it is reasonable to assume a powerplant weight, exclusive of the fuel which is considered to be the same as in the previous case, of

	Lb.
Engine	600
Engine Accessories	33
Starting System	17
Cooling System	0
Water	0
Dry Weight of Oil System	33
Propeller	58
Dry Weight of Fuel System	184
Engine Controls	15
Total Powerplant Weight	940

Owing to the simpler engine mounting required for the air-cooled engine, there will be an additional saving in the weight that is conservatively estimated at approximately 50 lb. The total saving in the powerplant weight in the case of the latter installation is, therefore

$$1462 - 940 + 50 = 572 \text{ lb.}$$

This saving in the deadweight of the powerplant permits an increase of 572 lb. in the pay-load, without in any way affecting the performance characteristics of the airplane.

Assume that a commercial transportation company has a regular contract to carry 3000 lb. of goods per day, a distance of 500 miles. To fulfill this requirement it will be necessary in the first case to keep three airplanes in continuous operation, while with the lighter powerplant the same work can be done with only two machines, and the relative transportation costs per ton-mile will be 50 per cent greater when using the heavier engine than when using the lighter one.

PROGRESS

A MEDIÆVAL mood of stagnation and apparent finish always precedes the discovery of our new worlds. Correct forecast of the future is so rare because it must be founded upon a disbelief in the stability of things as they are. The young and the speculative are always taken by surprise; but the experienced no longer count on continuity. The apparently so enduring structure into which we are born soon tumbles about our ears. And we, who at first seemed to be moving forward through a fixed world, finally come to regard ourselves as the only fixed thing in it. Life overleaps every bound that is set; and we have to keep advancing our landmarks.

We are born for the future and the past concerns us only secondarily.

To create and at the same time supply a new demand is the highest usefulness. The world wants it, yet never knows it.

Always the most precious gift is one of whose value the recipient is still ignorant. Conditions try to hold us in their service.

If we feel the world's needs, we shall be the right man at the right moment. But if we feel only our own, we shall at most be mental valetudinarians. Many look, one sees; many ought, one does. He is the great man.

Heaven still opens when the right voice vibrates; the rock still gushes when the prophet speaks.—S. B. Stanton.

Painting Practice from the Chemist's Viewpoint

By L. Valentine Pulsifer[1]

Detroit Section Paper *Illustrated with* Drawing

THE paper presented at the meeting of the Detroit Section held on March 2 was a resume and combination of the two papers presented by Mr. Pulsifer at the 1922 and 1923 Annual Meetings of the Society, entitled Manufacture and Application of Automobile Varnishes and Paints, and Automobile Finishing-Varnish, respectively. On account of this duplication, the paper actually presented at Detroit is not printed herewith but in lieu thereof abstracts of the two papers are given below with references to the issues of THE JOURNAL in which they were printed, so that members who desire to refer to the complete text as originally printed and the illustrations that appeared in connection therewith can do so with the minimum amount of effort.

The procedure following the presentation of the paper was based on a new plan. Cards were distributed among those present, it being asked that questions be written thereon by those who did not care to take part in the discussion orally. After the presentation of the paper the cards were collected and the questions were read by the chairman to Mr. Pulsifer who replied. For that reason most of the discussion appears in the form of questions and answers instead of in the customary arrangement with the names of the different speakers.

ABSTRACTS

DIVIDING the ability of an automobile finish to remain new into the elements of proper quality of the materials, engineering of application systems, methods of application and care of the finish, the author states that the responsibility for them rests jointly upon the manufacturer of the varnishes and paints, the builder of the automobile and the owner of the finished product. Five basic materials that are necessary in automobile painting are specified and discussed.

Engineering systems of application and the actual methods of application are treated in some detail, inclusive of drying, and of surfacing or rubbing. The care of the finish is important and the precautions necessary in this regard are outlined. The paper deals with the application and not the manufacture of the different varnishes and paints that are mentioned. —[Printed in the January, 1922, issue of THE JOURNAL.]

AS the success or failure of the finish of an automobile depends largely on the finishing-varnish, a plea is made for more scientific analyses of the problems of automobile finishing and more care in selecting and applying a suitable varnish. The qualities to be desired in a finishing-varnish are divided into two classes: the shop qualities and the service qualities. The shop qualities include color, body or viscosity, working, flowing, setting, hardening, fulness and the safety of working. The service qualities, or those that enable the varnish to withstand the various conditions of use, include resistance to break-down under the chemical action of the actinic rays of sunlight, to the destructive action of moisture and the alkalis in mud and soap, to expansion and contraction, to vibration and to abrasion. The three most important factors in estimating the service-giving qualities of varnish are said to be elasticity, moisture-resistance and the film factor. Each of the various terms mentioned is carefully defined, analyzed and explained. Among the constants that must be determined, either for checking uniformity or for use as bases of tests, are the non-volatile content, which is the starting-point in the test for elasticity and in computing the film factor or thickness of the dried film; the ash, the flash-point, and the acid number. An empirical formula is derived by which the thickness of the dried film can be estimated with accuracy; and in a series of appendixes the details are given concerning tests for the drying, the safety of working, non-volatile content, ash, flash-point and acid number; the Kauri reduction test; and tests for moisture and alkali resistance.—[Printed in the January, 1923, issue of THE JOURNAL.]

THE DISCUSSION

QUESTION:—What causes plain finishing to crack or craze on natural wood-wheels?

ANSWER:—The question, I presume, relates to premature cracking or crazing. Any plain or fancy finish will crack or craze eventually as a result of the chemical destruction caused by the actinic rays in sunlight. Premature deterioration may be due to a lack of elasticity in the finishing material or the use of a too elastic wood filler, with the subsequent finishing of those wheels before the filler was properly hardened. It may also be due to the building-up of the surface on which to apply the finishing with too much rubbing-varnish, instead of treating the parts the way a boat ought to be treated, that is, putting on none but durable materials. The proper way to finish wood wheels is very similar to the proper way to finish a boat. They should get a coat of suitable silex filler, which, if the job is to be tinted, is tinted to match the kind of wood wanted, and then be finished with three coats of a material that approximates a good spar-varnish in quality; if done in that way, the resultant finish can hardly crack and craze before its time.

QUESTION:—Why does enamel or paint peel on some metal? In other words, is there such a thing as pickled metal on which paint will not stick?

ANSWER:—Evidently something was wrong with the metal; it was pickled too much or it was not properly pickled. All metal does not take paint in the same way. This is especially true of steel; that is, some steels are much more easy to condition for painting than others. As a rule, steels that are capable of being properly drawn into panels show very much better characteristics for painting than the harder steels.

The only answer to this question is that the trouble might be due to 10 or 12 different things. The metal may have had grease-spots on it before it was finished,

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or incipient rust after the cleaning operation. Unless all the facts are known in a case like that, beginning with the analysis of the metal right straight through to the finish of the job, a specific answer to such a question can hardly be given.

QUESTION:—Which will give the more durable finish, (*a*) the use of an elastic color-sealer over the rough stuff, or (*b*) the use of a flat ground and the japan color over the rough stuff?

ANSWER:—The use of too elastic a pigment sealer-coat will cause trouble by being more elastic than the subsequent color-coats. My opinion is that a sealer-coat should be extremely thin and not relied upon to form the color ground-work as well as to perform the sealing operation; in other words, a coat that merely goes into the rough stuff or the surfacer and seals the pores, practically becoming a part of the rough stuff or the surfacer itself. With a sealer of this description it is possible to use a rough stuff of less toughness and more porosity and therefore easier surfacing qualities, than it is possible to use with good results if the sealer operation be omitted, because you really put the life into the rough stuff afterwards; after you have reached your surface.

There is no reason why a properly brought-up job in a japan color should not give perfect satisfaction. A job brought-up in a very elastic sealer-coat and then followed by a japan color would be very likely to cause trouble, just as one brought-up by the use of an elastic pigmented sealer followed by a more or less short, brittle color varnish, would be likely to cause trouble.

QUESTION:—Why does brass affect paint? How does enamel adhere to nickel or brass?

ANSWER:—Both copper and zinc, the largest constituent parts of brass, are difficult metals to paint. The combination is sometimes more difficult than either one by itself. Brass presents a more or less greasy surface and requires very careful surfacing and cleaning to get it in the shape to take primers properly.

Primers that are suitable for some other metals are not always suitable for brass or bronze. Sometimes it is quite a trick to get a primer that will give the best results on brass moldings or other brass parts. It is a question again of properly cleaning the material. Usually it is best to do the final cleaning with very fine sandpaper dipped in benzol, which gives a slight "tooth" to the brass part, and also makes it extremely clean; and then prime it before it has a chance to oxidize or tarnish.

QUESTION:—What is your opinion of viscosity measurement taken with the MacMichael instrument?

ANSWER:—The MacMichael instrument is too accurate and far too fussy for varnish work. In other words, it involves an unnecessarily fine operation. The best way of measuring the viscosity of a varnish is with the Gardner-Holdt viscometer.

QUESTION:—What viscosity should a satisfactory varnish have? Can a satisfactory varnish be made from materials containing an appreciable amount of rosin?

ANSWER:—The first question cannot be answered. There is no "best" viscosity for every type of varnish for every type of operation. To get the proper thickness of film on a flow-coated panel, a material of different viscosity from that required for brush work should be used. The same viscosity, as a rule, is not wanted in the under-coats as in the finishing-coat, and about the only thing to say is that the varnish should have the proper viscosity to give the best results under the conditions and methods of application.

In the case of a finishing-varnish the proper viscosity is the greatest viscosity that can be handled properly under the painting operation that is being carried on in a given plant; with the limitation that it must not be so great that the varnish from the top to the bottom of the panels does not harden through properly. In other words, if the varnish is too heavy, "case-hardening," with big alligator-cracks and checks, results long before the material should go to pieces.

Rosin is used in the varnish industry in a number of different ways. One of these is in the manufacture of the so-called resinate driers that are compounds of the rosin acids with various manganese, lead and cobalt salts, an indirect method by which these drier materials are frequently introduced into the varnish. These driers are very soluble and therefore can be introduced into the varnish much more easily than straight metallic driers.

Another use of rosin in varnish is that of the so-called ester gums that have as their basis the common South Carolina rosin treated with glycerine. This treatment produces a very low acid-number, and one that can be controlled. Varnishes of this class are particularly valuable as mixing varnishes for colors. The various natural gums have a wide range of acid number. No two lots will be exactly the same. If the gum, whether it is rosin or some other, is not treated in the same way, varnishes of fluctuating acid-number will be obtained and when they are compounded with various pigments fluctuating results will be secured. For that reason, for many types of mixing varnish, and for some other varnishes, a raw material that can be controlled through a chemical process that takes place in the plant itself can be used to good advantage.

QUESTION:—How does second-run turpentine compare with turpentine?

ANSWER:—The so-called first-run turpentine is better than the other because it is usually paler in color. It should be absolutely water-white. Second-run turpentine is very often somewhat off-color and contains a higher percentage of resinous material than the first-run turpentine. For many purposes turpentine should be just as near water-white as possible. In the case of second-run turpentine, where the resinous material is in excess it can be redistilled, and just as good results can be secured from second-run as from first-run by the introduction of this rectifying process. This is, of course, practical only where large quantities are used.

QUESTION:—Is it necessary to lay-up a winter supply of high-grade rubbing and finishing-varnish?

ANSWER:—Not as necessary as it was 30 or 40 years ago. The separation of the drier compounds of the rosin and the oil acids that formerly took place with alarming regularity when varnish was chilled is no longer anywhere near as likely to occur. This does not mean that it is not advisable to lay-in a stock if proper storage space is available. Under extreme low-temperature conditions the best material will occasionally show trouble from chilling.

QUESTION:—Is it possible to mix paint by the eye as nearly correctly as when using a scale and a measure?

ANSWER:—Yes and no, depending on the eye.

QUESTION:—Where can the bubble viscometer be obtained?

ANSWER:—The Gardner-Holdt bubble viscometer can be obtained directly from the Institute of Industrial Research, or by any varnish manufacturer for his customers. This apparatus was developed at the expense of the National Varnish Manufacturers Association. Only a limited number of the instruments can be produced by reason of the difficulty of getting tubes of standard internal-diameter; but they can be obtained from Dr. Harry

Gardner, of the Institute of Industrial Research, City of Washington.

QUESTION:—Can the Kauri reduction-test be used on any but the finish coat?

ANSWER:—Its principal value is in the estimation of the finish-coat, and of clear rather than pigmented varnishes, although, if it is possible with the color material to separate the pigment successfully, the Kauri reduction-figure can be determined for the remaining clear liquid.

In the case of rubbing-varnishes, the bulk of them crack on the bending-test without any Kauri reduction whatever. Merely the application of the original varnish, plus forced drying and the bending operation, will crack them. A reversal of the Kauri reduction-test on the rubbing-varnish can be made by determining the non-volatile content of the material and adding a mixture of bodied linseed-oil and turpentine to bring the varnish *up* to the breaking-point; by finding out how much of this oil compound it was necessary to add, the original elasticity or lack of it can be determined.

QUESTION:—Has the ultra-violet light been used commercially for drying varnish? Does it offer any possibilities?

ANSWER:—So far as I know the ultra-violet light has never been used for drying varnish. It has been used in an accelerated test for colored pigments, and in some research laboratories an attempt is being made to use it as an accelerated durability-test. It is a very good thing for finding out the fading or darkening quality of pigmented goods. It has possibilities in conjunction with the Kauri reduction-test, or perhaps by itself when used on completed systems, of simulating rapid "weathering" in the laboratory.

QUESTION:—Is there any standard method of testing the hardness of the varnish-film after it is dry?

ANSWER:—There is no standard method. One method has been proposed for use with such varnishes as those used on floors, and I presume it could be used for rubbing-varnishes. That is to buy a set of lead-pencils that run all the way from very soft to very hard; cut them down to a chisel-point; prepare the panel; give it the requisite time to dry; then, starting with the softest pencil, draw each of the series in succession over the panel and find out which one makes the first scratch. That sounds somewhat like a foolish method, but strange to say it works very well. As a rule that is not the kind of hardness that is in the mind of the man who is thinking of the hardness of a finishing-varnish. The only method of finding out whether it is hard enough is trying it in production. If it becomes gummed-up with finger-marks and things stick to it, it is not hard enough; if it goes through the regular schedule and does not have these troubles, it is hard enough.

QUESTION:—Do ovens heated to 110 to 120 deg. fahr. kill a large percentage of the oil in the varnish? If so, where does this oil go?

ANSWER:— It takes more than that to kill the oil of a varnish. The boiling point of the vegetable oils used in making varnish is something over 500 deg. A temperature of from 110 to 120 deg. fahr. merely results in a more rapid absorption of oxygen and a denser coat. In other words, it is wholly advantageous and not at all deleterious. Baking at this temperature, or perhaps a higher one, is deleterious only when a varnish that normally dries rather rapidly on the surface is run right from the finishing-room into a heated oven and is dried on the surface before the entire amount of the volatile material has been driven off. Then case-hardening, which is just the reverse of what is wanted, results. A temperature of from 110 to 120 deg. never hurt the life of any varnish under normal conditions.

QUESTION:—Will rubbing-varnish, when not thoroughly dry, cause the finishing-varnish to lose its luster?

ANSWER:—It certainly will; and the same thing will happen with any of the under-coats. The proper result with any conceivable system is based on the proper hardening of each individual coat, all the way down to the priming-coat.

QUESTION:—Can you approximate the number of coats of finish of an automobile body by visual inspection?

ANSWER:—I wish I could. I have seen some jobs that had 15 or 20 coats that looked very poor, and I have seen other jobs with only a few coats that looked fine. In other words, there is no way of measuring the thickness of a thing that you cannot see through without getting through and measuring it.

QUESTION:—Why does paint perish on aluminum more quickly than on steel?

ANSWER:—A certain paint system might perish more rapidly on aluminum than on steel, due to the different coefficients of expansion of aluminum and steel, but no reason in the world exists why an aluminum body cannot be painted to stand-up just as well as one of steel. The only precaution to be observed is not to permit anything in the nature of white-lead to touch the aluminum body, as, if the moisture gets through to that particular coat, it will cause corrosion, perishing and the disappearance of the entire finish. Aside from that there is no reason why a paint job should not last as well on aluminum if the job is properly balanced in elasticity for that particular metal.

QUESTION:—Why does an automobile body that has received a flow-coat job often check or crack near the bottom after several months' exposure to the weather, while the center and top are unaffected?

ANSWER:—That is due to the fact, especially where the flow-coat is used on the rubbing-coats, that the coats at the bottom of the panel are too thick to harden through properly. Then we have the effect of a hard material on top of a soft material, with the result that we get big alligator cracks, starting at the bottom and gradually working their way up.

That can be demonstrated very easily in the case of some flow-coated color varnishes the day after they are put on, by starting a putty-knife up under the coat. It is possible to go about one-third of the way up a door panel before reaching a point where the varnish is hardened through and cannot be removed. In a flow-coated panel the middle is about the normal thickness of a brush coat, so that the bottom is too thick, the middle is about right and the top is too thin.

QUESTION:—What effect do body polishes or automobile soaps have on the finish of a car?

ANSWER:—These two substances produce two different effects, as a rule. Some body-polishes have no deleterious effect, if they are properly used. The chief difficulty with these materials is due to the fact that there are many on the market that are merely thrown together without any regard to what they are apt to do to the finishing-varnish. They often contain abrasive material. Some are properly made, but if the directions on the can or the bottle are followed the finish will be ruined. They are sold as "dry washes," which are supposed to obviate the use of the hose. We are instructed to take a piece of cheesecloth with some of this substance on it and wipe off the mud. The result is, of course, that the mud gathers on the cloth, abrading and scratching the surface. These scratches and abrasions very soon develop

into checks and cracks and, with the expansion and contraction of the surface, the job is naturally rapidly ruined.

As far as soap is concerned, the same oils that are used in making soaps are used in making varnish. If a soap contains free alkali, and most soaps do, when it comes to cutting the oil and the grease, and they are used on the finish-coat to excess, or improperly, they will naturally tend to destroy the life of the finish by a gradual chemical action of the alkali on the oils in the varnish.

QUESTION:—What is the proper way of preparing a surface for the primer coat?

ANSWER:—I believe that nothing can compete with the properly dried sand-blast. Many shops have not a proper sand-blast, and there some other method is necessary. Some materials, used for removing rust, cut deep into the rust and take it off. If those materials are themselves subsequently removed or washed off with a material like benzol, and the job perhaps sprayed with superheated steam and then coated as soon as it is dry, good results can be secured without the use of a sand-blast.

Other methods that are used lead to trouble. One of these is the use of the so-called gasoline that we get now as a final and complete wash for automobile bodies. The ordinary gasoline of today contains considerable high-boiling material that used to be sold under the names of kerosene, cylinder and fuel oils and road tar, and it is a risky thing to use. A better method, by far, is to use benzol or denatured alcohol, or perhaps give a final wash with these materials after using the gasoline.

QUESTION:—Will an all-metal body ever be finished in color and baked at a high temperature?

ANSWER:—"Ever" is a long word, and if that is the crux of this situation I will say "yes"; but when, I do not know. It is also a question, I think, of whether everybody wants to ride in an all-metal body. The wood frame on which the usual body is built is a wonderful deadener for rattles and other noises. While certain cars will undoubtedly eventually come to an all-metal body and be finished with black material, or possibly some day with a colored material, I think there are features of the all-metal body that will have to be considered in addition to the question of whether color of a suitable kind can be baked on it. For certain production purposes the all-metal body is advisable and the proper way to finish it is with a material that can be baked-on at temperatures which, the body being all metal, we can afford to use.

QUESTION:—To what extent is China wood-oil used in finishing-varnish?

ANSWER:—It is used to a large extent blended with linseed-oil. China wood-oil appeared on the varnish-chemist's horizon about 20 years ago; in many cases it was originally seized on as a material for making cheap varnishes that would dry and harden rapidly. However, it possesses very many valuable features. It has a toughness and resistance to moisture, as well as a resistance to alkali, that linseed-oil does not possess. Most of the good varnishes today are a combination of linseed-oil and wood-oil, the particular combination used in any given varnish varying according to the service to which the varnish is to be put.

QUESTION:—Is varnish affected by atmospheric pollution in districts where there are coke-ovens and coaltar by-product plants?

ANSWER:—I think there is no question that if the atmosphere contains a large amount of elements such as are present in the air around coke-ovens, blast-furnaces, cement plants or chemical works, these materials are carried down with the rain onto the body and very often help to stain, and sometimes to destroy, finishing-varnish.

QUESTION:—Why does not varnish last as long as it used to?

ANSWER:—This has a sort of familiar sound. The answer is that it does and it does not. Today it is possible to obtain varnishes of at least double the durability of the best varnish that existed in the heyday of the old carriage-business. But, who ever saw a Brewster brougham going down a side street at 60 m.p.h.! It would not have lasted as long as the varnish. In addition to the much greater severity of service on the modern automobile in many cases varnish is used on automotive work that the old carriage-builder would hardly have used for quick repair-work. In other words, to get by on somebody's schedule, or somebody's idea of drying time, or somebody's idea of price, varnishes are used today to finish automobiles that are far inferior in elasticity and durability to the best grades of carriage varnish. The automobile is out more of the time; it is driven faster; it is washed more carelessly; it is soaked with the fumes of gasoline and smeared with oil and grease. Thus the varnish does not begin to have the chance it had on the old carriage, which was lovingly cared for by some coachman who had been with the family for many years.

On the other hand, varnishes of at least double the durability that we used to get can be procured, although of course no varnish today, on an average automobile, can outlast the best finishing-varnishes on the carriage of 50 years ago, simply because the use to which the article is put is very much more severe. However, we can double, treble and quadruple the durability of the usual automobile-finish by using the best materials and methods available.

QUESTION:—Should varnish be aged by the motor-car builder? If so, why?

ANSWER:—If he buys "that" kind of varnish he ought to age it, but the proper answer is "no." There is no reason in the world why the automotive manufacturer should buy varnish that he has to age. The material is supposed to be ripened and aged properly before it is sent to him. Ageing in the shop is not very likely to help. The use of an unripened varnish is not advisable from any angle.

QUESTION:—Will varnish age in a can after it is cured, or must a certain percentage of oxygen be allowed to get into the tank to age it?

ANSWER:—It is not necessary to allow a certain amount of oxygen to get into the tank to age the varnish. If the tank is constructed so that a large amount of oxygen can reach it, and the varnish is kept there long enough, it will not only age but get "past the cure"; it will absorb so much oxygen that it will lose a certain amount of its initial life before it ever goes on the job.

The destruction of the varnish is a progressive oxidation. This progressive oxidation on the job is accelerated by the chemical rays in the sunlight and by moisture. If we start this oxidation by admitting too much air to our tank, or, as some do, by using blown oil instead of heat-bodied oil in the varnish originally, we set up a condition that is bad and leads to premature perishing. A perfectly sealed can of varnish that was properly aged when the can was first filled will keep indefinitely if stored under the proper conditions.

We had a case many years ago of a shipment of varnish sent to China. After keeping it out there 30 or 40 years the Chinaman wrote that there did not seem to be a ready sale for this material in China, and he wanted to know whether we would be willing to take the ship-

ment back and exchange it for house paint. So the material was sent back to us and, although it left the plant several years before I was born, I enjoyed testing it when it arrived. Both the body-varnish and the rubbing-varnish were in perfect condition. This old fellow had evidently kept the material in a proper kind of place. It had not chilled. If there had been the slightest oxygen leak, the varnish would have been ruined for use, years previously.

QUESTION:—What effect will a mixture of banana oil and alcohol have when used as a body polish?

ANSWER:—Banana oil is amyl acetate, which is a fine solvent for every kind of gum, oil and everything else that ever went into a varnish. Mixed with alcohol it forms about as destructive a combination as anybody could get, other than putting in a little TNT to go along with it.

QUESTION:—What makes a body change color under rain?

ANSWER:—The bluish appearance that is seen on most automobile bodies if it rains on them long enough is due to the absorption by the finishing-varnish of a small amount of moisture. When this moisture is in the finishing-coat we get a white appearance due to the optical effect of having two things of different refractive value together; particles of water mingled with particles of varnish. In some cases, if the rain lasts long enough, the white appearance becomes permanent; but ordinarily it disappears with the first sunshine. If a bottle half-filled with, say, water and benzol, two perfectly clear liquids, that would correspond to perfectly clear varnish and rain water, is shaken vigorously, while the liquids are mixed they will appear white, whereas neither one of them has changed color in the least. The same effect takes place when the body-varnish absorbs moisture, and it disappears when the moisture disappears, just as the two liquids mentioned will separate and both be as clear as ever.

The permanent whitening that occasionally takes place on automobile varnish is due to a chemical change in the varnish induced by either prolonged or frequent wetting. In that case the drier compounds of the varnish take on a molecule of water and become hydrated. In that hydrated condition they are actually white and opaque.

QUESTION:—What makes the outer coat or finishing-varnish peel off after the first year?

ANSWER:—Many of the varnishes used as a finish-coat are lucky to get by the first half-year, although usually the peeling off of a varnish is a kind of destruction that ought not to take place. If the under-coats are proper and the last rubbing-coat is properly surfaced before the finish is put on, the varnish ought not to peel off. It should perish gradually. The actual peeling is due to some condition under the finish, for which the finish itself is not to blame.

QUESTION:—What effect has salt water on paint?

ANSWER:—That depends on the pigment that is contained in the paint. On the varnish itself salt water has not as great an effect as fresh water, for the reason that salt water, due to the salt-content, does not penetrate the varnish-film as readily as pure distilled water. The allegation that salt water is harder on varnish than fresh water is due to the fact that many of the varnishes used on vessels on the seacoast do not last as well as the same materials used in varnishes for boats on inland waters. This is accounted for by dry salt, which acts as an abrasive, being deposited by the salt water on the deck and the rails, rather than by the action of the salt water as such. Fresh water will affect varnish, and usually paint, more rapidly than salt water.

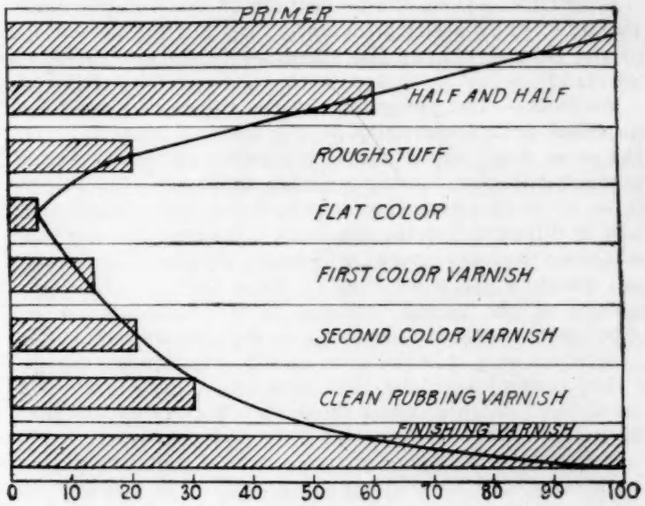

FIG. 1—CHART SHOWING THE PROPER CORRELATION OF ELASTICITY IN THE VARIOUS COATS

QUESTION:—If the first and last coats give the best results when they are 100 per cent elastic, should not the center coats be more than from 10 to 15-per cent elastic?

ANSWER:—Taking into consideration the number of coats it is necessary to put on an automobile, if an absolute parity of elasticity from the top to the bottom were maintained, the results would not be as good as those given by the curve in Fig. 1. If all these coats had exactly the same elasticity, the result would be as shown. The top coat, of course, gets the bulk of the wear-and-tear, and the bulk of the chemical rays of the sunlight, and the progressive oxidation or rotting goes on more rapidly in the case of the top coat than of those underneath. If all the coats had the same elasticity, the last one would reach a low point of elasticity before the next underneath did, and considerably before the second one underneath, and we would set up in our system the same result that we would get if we upset this elasticity curve to start with. In other words, the finish might, and probably would, go to pieces more quickly if all these coats were of the same elasticity, than they would if we had a proper gradation in elasticity from the primer to the finish.

When it comes to a boat, or a front door, the operation consists of only three or four coats, and it is safe to use these three or four coats of the same elasticity. I believe that is the best practice in such a case. The best way to finish a boat is the best way to finish the wood wheel I spoke of at the beginning of this discussion; that is, put on a proper filler, and then three coats of the same material; that does not apply to a system made up of five different types of material, consisting of from 5 to 10 or 12 coats.

QUESTION:—Should the user inspect his paint and varnish?

ANSWER:—If he is equipped to do so, yes; otherwise he would be wasting his time. I do not know of any industry in which the user of any material ought not to be equipped to test it. I would hate to run a varnish factory if we did not have well equipped laboratories in which to test all the materials we use. The same thing applies to an automobile factory or any other large industrial organization.

QUESTION:—Does the percentage of non-volatile material affect the elasticity factor? Does not the percentage of the thinner change the elasticity factor for the same varnish?

ANSWER:—The percentage of the thinner in itself has no effect on the elasticity of the residual material. On the other hand, the ultimate durability of the finishing-varnish will vary directly with its thickness. Therefore, if we have two varnishes in which the non-volatile content is different but the elasticity the same, the one that will yield the heavier coat will retain its elasticity longer, and consequently wear longer. To a certain extent, the amount of the volatile content of the material has an effect on the ultimate elasticity on the job, although it is an indirect one; it is easier to oxidize completely through a thin coat of material than through a thick one. By "oxidation" in this case I mean the final oxidation that takes place when the varnish rots and perishes.

QUESTION:—Is it good practice to heat metal to reduce the strains due to cold-punching and other mechanical operations, and cool slowly before applying paint coats?

ANSWER:—I doubt it. Unless the metal as designed sets up such strains that it is likely to pull apart itself, the amount of strain that it can induce in the finishing-coats due to its not being properly annealed would be absolutely negligible. The fact that varnish goes to pieces on the cowl of an automobile more readily than on the rest of the car is due entirely to the angle of exposure and not at all to the internal stresses or the actual or imaginary porosity of the material. As a matter of fact, the more porous it was, the better shape it would be in to take the primer. No matter how porous it became, it could hardly become as porous as the wood that formerly was used for the same purpose and gave great satisfaction.

QUESTION:—What is the best method of eliminating mud-spotting on finishing-varnish?

ANSWER:—There are certain exposures to mud that will spot almost any varnish, even the most waterproof material used for a chassis. If mud of a very alkaline nature gets on the varnish when the latter is fresh, and is left on until the mud dries to a thoroughly hard cake, it will leave a spot that will sometimes disappear, and sometimes will not. On the ordinary job, that is anywhere near properly cared for, sunlight as a rule will remove the spots; if not, wiping off with the material that used to be known as lemon oil will usually take out the spots. Sometimes it requires more than one operation to do this. The only way to get rid of those spots is to dry-out the moisture that caused them.

QUESTION:—What is your opinion of the humidity control in the accelerated drying systems?

ANSWER:—The humidity certainly should be controlled in the accelerated drying systems, although, when the materials are dried at low temperatures, which are commonly used, the addition of humidity is not as necessary as is sometimes supposed; but if the higher temperatures are used, it is necessary to have a certain amount of humidity in the air to hold back the evaporation of the volatile material. In other words, if a car were rushed into a very hot oven that was absolutely dry, the solvent would try to "jump out" at once, and the case-hardened effect would naturally follow. The use of humidity is to hold back the evaporation of these solvents; to give the job the proper chance to season through. Of course if humidity is used, it should be under control.

QUESTION:—What causes float in color varnishes?

ANSWER:—To get the desired shade many color-varnishes contain several different pigments. Hardly any two pigments are of the same specific gravity. The light ones tend to come to the top, and the heavy ones to go to the bottom. The result is a float that sometimes causes trouble. The proper balancing of the different pigments, keeping them as close together in specific gravity as possible, their extremely fine grinding and the proper application are the only things that will avoid trouble in a color that is likely to float. The trouble usually appears when one part of a panel is brushed very much longer than the other, and more of the light-weight material is taken off one part of the panel than the other, thereby producing various shades.

QUESTION:—Is varnish a mechanical mixture of the molecules of the gum and the oil? If so, what are the molecules in chemical symbols? If not, what is the symbol of a molecule of varnish? Can you show by chemical symbols the change that takes place in varnish as it is drying, and again its condition when it gets old and is cracking?

ANSWER:—The question of whether varnish is a mechanical mixture or a chemical compound or merely a colloidal suspension is one that is still up for debate. Some parts of the varnish are mechanical mixtures, some are chemical compounds and some are undoubtedly colloids. Exactly which is which is very difficult to say. The combinations of the metallic driers and the oil and the rosin acids are definite chemical compounds. Whether there is a chemical reaction between the gums and the oils is not always apparent. No chemical action takes place between the thinners and the gum-oil base of the varnish. The only way to keep such a collection as that under control is to watch every step in the manufacture with extreme care.

QUESTION:—Why is it necessary to reject varnish after experts have tested and shipped it?

ANSWER:—It is not always rejected by experts. Or the experts who originally passed it may not have been as expert as they were supposed to be. Some varnish is rejected that should be retained and some varnish is retained that should be rejected.

QUESTION:—What is an ideal baking-temperature for black japan or enamel on metal, considering cost, quality and durability?

ANSWER:—I do not feel very well equipped to answer that, as I have had very little experience with materials of that sort.

QUESTION:—What are the characteristics of a good wheel-primer?

ANSWER:—A good wheel-primer is one that sticks to the wheel and allows the subsequent coats to stick to the primer. A good wheel-primer as a rule should be a clear material, to allow inspection of the wheel after it arrives at the automotive plant. It should be a primer that naturally will adhere properly to the wood and have the requisite elasticity and hardness to take the subsequent coats. This refers to wooden wheels. Practically the same answer would hold good for metal wheels, although in that case it does not make any difference whether the primer is clear or pigmented.

A. I. STEVENS:—There seems to be a strong demand from the automobile body-builder to standardize more or less on paint-shop practice and the materials used therein. In view of the variables in the manufacture and testing of varnishes themselves, would it not be difficult to accomplish the standardization for which the body builders are striving?

L. V. PULSIFER:—By that do you mean standard specifications for material or something of that sort?

MR. STEVENS:—Standard specifications with regard to

viscosity and a printed standardization of quality of the varnish itself.

MR. PULSIFER:—I think the whole question of what is the best varnish for any given purpose is still too much involved to talk very strongly about writing automotive-varnish specifications. The United States Government has written very many varnish specifications; some have been good and some have not; but I never have heard that the use of those specifications has been of any great help. An automobile varnish is a complicated thing. When it comes to a product like exterior house-paint, it is usually easier to write specifications that will be of some value, and that can be checked up. When it comes to the specifications written by an automobile builder for a given varnish or a paint material, I think the state of the art in the automotive industry today is at a point where those things are likely to cause more trouble than good. However, the automotive company or the user of any of these materials should most certainly know what the various desirable qualities of varnish are. They should have within their personnel some one who is equipped to make proper estimates; but drawing definite specifications, that the gravity and the viscosity shall be such and such, winding up with material specifications of some sort, as a rule leads to more trouble than value.

The user of the product should cooperate with the people from whom he is trying to buy it, and work out the best material for his particular operation for the particular thing he is trying to arrive at; and then have within his possession the necessary knowledge to check deliveries against the data arrived at under that cooperation.

MR. STEVENS:—I find that I agree with Mr. Pulsifer after all.

E. PLANCHE:—With the instructions that Mr. Pulsifer has given us, together with a good quality of material, under the present use of an automobile in all kinds of weather, how long should the luster on the finish of the body last?

MR. PULSIFER:—An arrangement such as is shown in Fig. 1, with a varnish that showed 100-per cent reduction with the Kauri test, a properly engineered system and anything like decent care, should go safely through at least a year. Most automobiles at the end of a year have been scratched, bumped or dented to such an extent that they require refinishing. A system such as that referred to in which, as I say, the final coat was between 80 and 100 points in elasticity, ought to go through a year to a year and a half in normal use. Of course, under abnormal use or under abuse that time might be reduced to a few months or even a few weeks. It is possible, by beginning to increase the elasticity of the material in the rubbing-coats and reaching an elasticity in the last coat before the finish of say 70 or 80, and then putting on a finishing-varnish of an elasticity that is practically double the normal amount, to run that life up to 2 or 3 years with anything like good service conditions. Of course, many jobs are so engineered and so finished that if they were finished with the *A* varnish in Table 1 that had an elasticity factor of 10, a rather thin film-factor of 35 and a total estimated service figure of 45, the expected life could not exceed from 4 to 6 months at the best, especially on the parts of the job that were exposed flat or up to about 45 deg.

TABLE 1—SERVICE-DURABILITY RATINGS OF FOUR FINISHING-VARNISHES

Finishing-Varnishes	*A*	*B*	*C*	*D*
Elasticity Factor	10	60	90	160
Moisture Resistance	0	10	20	50
Film Factor	35	47	52	36
Service-Durability Rating	45	117	162	246

RESERVE-RATIO OF FEDERAL RESERVE BANKS

THE amount of reserve required for a bank that is a member of the Federal Reserve System depends on the size of the community in which the bank is located and the nature of its deposits. On the average throughout the country the reserve required for a member bank is about 10 per cent of the amount of its deposits payable on demand. In the same way, Reserve Banks must keep in reserve a certain proportion of their funds, and because of the fact that the Reserve Banks carry reserves for other banks, the percentage is much higher, 35 per cent of the amount of their deposits, and 40 per cent of the amount of their notes; but for purposes of convenience and ease of reference the published reserve percentage is a single figure. This figure is the proportion that the total reserves bear to the amount of both deposits and notes. Thus a 75-per cent reserve-ratio or percentage means that the Reserve Banks have reserves in gold or lawful money that amount to three-quarters of the sum of their deposits and notes.

The reserve-ratio of the Reserve Banks may therefore be affected by any one of three factors, a change in the amount of cash reserves, a change in the amount of note issues or a change in the amount of deposits. Changes in the cash reserves, however, affect the ratio more than do changes in either of the other two items.

Present conditions are not such that the gold reserves of the Federal Reserve Banks remains stationary. In the past 2 years it has increased more than $1,000,000,000, practically all of which represents importations of gold. In the early stages of the gold movement, when the gold found its way into the Reserve Banks it paid debts owing by the member banks; latterly it has permitted the member banks to increase their deposits to the highest point ever reached and at the same time to maintain the reserves that the law requires with very little borrowing from the Reserve Banks.

The combined effect of these huge gold imports, increasing the reserves, and of simultaneous heavy redemptions of Federal Reserve notes, decreasing the liabilities, has been to bring about the present reserve-ratio of approximately 77.0 per cent, which compares with the ratio of 85.0 per cent when America entered the war and the ratio of 42.5 per cent in the autumn of 1920 when the credit strain was at its peak.

The present high reserve-ratio, then, is in large part due to the recent flow of gold to the United States from countries that for the time being are not on the free gold basis that obtained before the war. A return to such a basis, under which gold would flow back freely into or out of such countries in settlement of international balances, would, if our balances were adverse, cause a corresponding outflow of our gold. This would decrease our reserve-ratio, exactly as recent imports have increased it.—*Monthly Review.*

Safety and Comfort as Inducements to Air Travel

By R. R. BLYTHE[1]

ANNUAL MEETING PAPER

ASSUMING that flying-boat service is safe, the author enumerates some of the reasons people hesitate to fly, inclusive of the difficulty of reaching an airport and the inconveniences of embarking. He states that when the danger to which the passenger believes he is exposed is added, the total deterrents constitute a considerable preventative of the adoption of aviation by the public.

He adds that the recent issuance by the insurance companies of what might be termed a bet of $25,000 with any adult who will fly, at odds of 1000 to 1, that he will arrive safely at the destination, is proof that flying in a sound commercial seaplane is safe at present, and he believes the same guarantee could be secured from insurance companies for airplane passengers flying along properly organized routes over land.

THE average person believes that aviation is a hazardous occupation to be connected with. When he is invited to fly, his usual first impression is that he is going in for an experience that he probably will not have again. He takes the opportunity of going through what he considers a thrilling experience so that he will be able to tell his acquaintances that he has flown in the air. It is conceded by everyone in aviation that thousands of people have flown, and this is a simple concession when one stops to consider that there are at least 100,000,000 people in the United States who could fly as passengers. But, out of that number, the few thousands who have flown do not make up a very remarkable percentage.

How much serious thought has ever been given to what are known as the "repeats"? By repeats I mean persons who having flown once, let us say for business reasons, find this mode of travel economical, fast and comfortable and are willing to undertake other flights for the reason that such flights are beneficial to their business. I think that it will be found that the majority, if not all, of the people who have flown once to get this experience have not undertaken a second flight. There must be a reason for this. We all know that aviation is comparatively safe; so, for the sake of argument, let us forget the question of safety in aviation and confront ourselves with the problems that are likely to affect the mind of the average person.

First, there is the difficulty that prospective passengers have in reaching the flying-fields or airports. Perhaps this is the most vital of all the business-getting problems. Few members of the traveling public are willing to sacrifice themselves in any way in traveling by an interurban trolley-car or an automobile to some landing-field that is on the edge of the suburbs of a city. If the day is cloudy, cold or rainy, there are even greater difficulties such as muddy grounds, the possibility of not being able to fly and the discomforts that accompany bad weather. Thousands of people have not flown and have not even seriously considered flying on account of this alone. A taxicab will call at their door and deposit them inside a warm, well ventilated and well lighted railroad station where their train waits with all the modern comforts. Consider the modern railroad station for a moment and compare it with the modern airport. Is there any inducement to fly?

Second, the passenger arrives at an airport fully prepared to fly, and pays the rather excessive rates that are charged for air travel. In the case of seaplanes, he has to climb aboard a small open boat and, after much shouting and hauling around the bay, the boat finally draws up alongside the seaplane from which are issued the admonitions to the boatman: "Be careful. Do not bump the wing. Swing around and try it again. Hold it off the nose," and several other cautionary orders to keep the boat from breaking what the passenger believes to be a sound, stable aircraft. Finally, after swaying and swinging to-and-fro, he performs an acrobatic feat and gets aboard the seaplane. In the case of airplanes that take-off from a landing-field, the passengers, aided by the pilot, climb up a rather rickety ladder from uneven ground into a cabin having exceedingly close quarters for a limited number of passengers. The roar of the engine is to be considered and also the various inconveniences of taking-off; as well as the troublesome form of exit after landing. Adding to these deterrents the danger that the passenger believes he has been undergoing, we have a considerable setback for the adoption of aviation by the public.

DANGERS OF FLIGHT

How dangerous is it to fly? The insurance companies recently have issued what might be termed a bet of $25,000 to any man or woman who will fly, at odds of 1000 to 1, that he or she will arrive safely at the destination. The effect of such a bet as 1000 to 1 is to prove that flying in a sound commercial-seaplane line is safe at the present stage, and that this rate will be reduced even further after future experience. Properly organized airplane-routes over land, having a sufficient number of intermediate emergency landing-fields, could easily secure this bet of 1000 to 1 on the safety of airplane passengers.

We must "boost" aviation by all means and impress the public with its safety and its speed, but we must find ways and means to overcome such obstacles as we are facing at present that really have nothing to do with the construction of planes themselves. We have sufficient aircraft speed and safety, but we do not have the conveniences. Without the conveniences, the public will not consider flying.

[The discussion of this paper is printed on p. 352.]

[1] Aviation insurance manager, Johnson & Higgins, New York City.

Motor-Transport Performance with Varied Fuel-Volatility

By C. T. COLEMAN[1]

SEMI-ANNUAL MEETING PAPER *Illustrated with* CHARTS

THE paper is a presentation of data obtained regarding the economic operation of motor vehicles with fuels of varied volatility, under service conditions. The entire fleets of motor-transportation units used by the Post Office Department in Philadelphia and in Pittsburgh were made available for these tests, the resulting data being summarized in the tables and charts, and commented upon briefly.

The test procedure is described and the method of examining the used-oil samples for the percentage of dilution, changes in viscosity, flash-point and fire-test, is explained, inclusive of the tabulated results.

While the results may not hold true for cold-weather operation, they show that the number of car-miles per barrel of crude oil increases as the volatility of the fuel decreases, over the range of fuels used. This is true because the percentage of production per barrel of crude oil is increased, while the number of car-miles per gallon of fuel is not affected materially by the variation in the volatility as represented by the four fuels used.

IN order that natural resources might be conserved and the ever-increasing number of motor vehicles supplied with fuel, every effort has been made in the past few years to refine all the gasoline possible from each barrel of crude oil and still furnish a satisfactory fuel. If a fuel of higher end-point, or lower volatility, could be used economically, gasoline production could be increased, thus postponing possible future shortage.

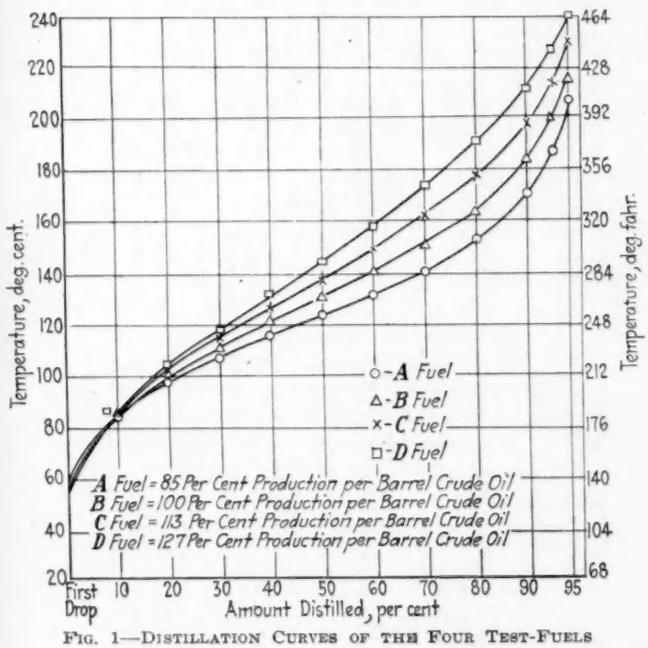

FIG. 1—DISTILLATION CURVES OF THE FOUR TEST-FUELS

TABLE 1—CLASSIFICATION OF THE FLEET UNITS

Philadelphia			Pittsburgh		
Number of Vehicles	Size, Tons	Make	Number of Vehicles	Size, Tons	Make
37	⅜	Ford	42	¾	White
82	¾	G.M.C.	16	2	White
31	1½	G.M.C.	16	3	Riker
13	3	Packard	....	....	.....

To the end that some information might be available regarding the economic operation of motor vehicles with fuels of various volatilities, it was believed that a series of tests made under service conditions would furnish valuable data.

A request was therefore made to the Post Office Department for cooperation in a test of this kind. That Department readily agreed and placed at the disposal of the Bureau of Standards, for the purpose of test, its entire fleets of motor-transportation units in Pittsburgh and in Philadelphia. Much credit is due the Post Office Department and the personnel at Pittsburgh and at Philadelphia for the manner in which these tests were conducted. The personnel of the fleets in both these cities made every effort to cooperate with the Bureau of Standards' representative, and the results obtained are a tribute to the efficiency of the personnel conducting it. The combined fleets represented some 237 units of transportation, classified as shown in Table 1. The Philadelphia fleet consumes approximately 1000 gal. of fuel per day, while the fleet in Pittsburgh requires approximately 700 gal. of fuel per day. This combination presented two excellent features; first, a rather large number of trucks well divided in respect to tonnage and make; second, two distinct types of operating conditions, inasmuch as Philadelphia has comparatively smooth streets with few hills, while in Pittsburgh the majority of the streets have a very rough surface and there are many hills.

After a conference with representatives of the American Petroleum Institute, the Society of Automotive Engineers, the Bureau of Mines and the refiners, it was

TABLE 2—ESTIMATED PRODUCTION OF THE FOUR TEST-FUELS

Refiners	Grade *A*, Per Cent	Grade *B*, Per Cent	Grade *C*, Per Cent	Grade *D*, Per Cent
1	81	100	114	128
2	91	100	111	124
3	83	100	113	122
4	84	100	115	133
Average.....	85	100	113	127

[1] M.S.A.E.—Associate mechanical engineer, Bureau of Standards, City of Washington.

TABLE 3—TEST RUNS IN PHILADELPHIA FOR 4 WEEKS ON THE ECONOMIC VOLATILITY OF FUELS

Section No. 1						Section No. 2					
Car No.	Service Rendered[2]	Fuel Consumption, Miles per Gal.				Car No.	Service Rendered	Fuel Consumption, Miles per Gal.			
		First Week Grade *B*	Second Week Grade *B*	Third Week Grade *B*	Fourth Week Grade *B*			First Week Grade *B*	Second Week Grade *A*	Third Week Grade *C*	Fourth Week Grade *D*
Ford Cars						**Ford Cars**					
500	(1)	N.S.	10.19	11.13	13.35	1,708	(5)	13.84	13.54	13.31	7.50
501	(2)	9.73	14.95	7.42	7.12	1,710	(5)	9.06	7.51	7.80	9.49
502	(3)	7.16	9.38	7.20	N.S.	1,711	(5)	12.31	12.04	11.26	10.83
503	(1)	N.S.	12.38	11.43	11.23	1,712	(5)	11.97	17.24	17.18	14.18
504	(1)	8.43	8.73	7.62	7.66	1,714	(5)	13.80	12.14	13.40	14.44
505	(2)	9.58	8.44	8.70	7.22	1,715	(5)	8.00	8.20	10.34	10.37
506	(3)	8.88	12.37	9.88	4.60	1,716	(5)	7.71	7.89	N.S.	N.S.
509	(1)	7.83	8.26	9.02	8.47	1,717	(5)	10.56	11.90	11.84	12.54
510	(3)	11.36	9.76	8.37	8.32	1,718	(5)	8.41	9.08	9.67	9.90
511	(3)	7.30	6.14	8.00	11.69	1,719	(5)	9.96	9.72	10.15	9.26
512	(2)	8.71	7.42	9.61	8.93	1,720	(5)	5.40	11.58	14.08	12.84
513	(1)	14.54	11.27	11.30	11.09	1,721	(5)	8.95	9.31	8.72	8.96
514	(3)	8.84	8.00	N.S.	6.59	1,722	(5)	10.87	12.81	9.88	11.58
515	(3)	9.82	N.S.	N.S.	N.S.	1,723	(5)	8.53	7.44	8.77	9.40
846	(2)	7.25	6.71	6.48	6.74	1,724	(5)	12.32	12.91	9.06	10.79
847	(3)	8.31	8.62	8.23	9.16	1,725	(5)	7.74	9.76	11.26	11.30
850	(2)	6.22	4.83	6.10	9.03	1,726	(5)	11.77	13.16	11.63	11.11
1,729	(5)	12.48	11.42	11.93	10.51	1,727	(5)	9.98	9.52	8.37	9.46
S-100	(4)	11.83	6.25	10.29	8.67	1,728	(12)	8.32	9.11	7.09	10.62
¾-Ton G. M. C. Trucks						**¾-Ton G. M. C. Trucks**					
2,663	(6)	7.82	10.41	7.92	7.00	2,332	(7)	10.69	10.82	13.51	10.94
2,664	(7)	7.62	8.54	9.43	9.17	2,333	(7)	8.91	10.34	10.51	10.00
2,665	(7)	9.20	8.97	8.06	11.60	2,334	(7)	5.77	6.98	8.22	11.11
2,666	(6)	8.99	9.72	9.80	9.44	2,335	(7)	10.86	8.08	7.45	6.58
2,667	(6)	11.10	8.99	8.77	8.68	2,336	(3)	9.92	6.97	6.14	5.45
2,668	(6)	9.98	11.79	12.53	13.59	2,419	(7)	6.29	6.36	9.54	7.50
2,669	(6) and (8)	8.07	8.29	8.44	9.63	2,422	(7)	5.93	5.79	6.18	5.57
2,670	(8)	5.74	5.81	6.89	6.50	2,423	(7)	7.36	6.32	4.40	7.63
2,671	(8)	8.76	5.50	6.40	5.33	2,424	(7)	7.17	7.02	7.39	7.28
2,672	(6)	7.10	6.35	6.06	6.00	2,425	(3)	N.S.	6.70	3.41	8.60
2,673	(8)	11.44	5.42	6.02	5.73	2,426	(3)	7.35	N.S.	6.67	5.85
2,674	(6)	9.91	7.30	6.65	7.06	2,427	(3)	9.46	8.52	8.48	9.00
2,675	(6)	9.75	6.94	7.93	9.19	2,428	(3)	4.67	4.56	10.47	5.63
2,676	(1)	5.80	4.28	5.64	4.96	2,429	(7)	9.04	8.62	8.94	9.84
2,677	(2)	8.10	9.27	8.91	8.14	2,430	(7)	6.94	6.70	7.50	7.46
2,678	(8)	3.08	8.51	7.95	5.70	2,431	(7)	7.02	8.82	6.94	9.02
2,679	(2)	5.48	7.74	7.72	8.31	2,432	(7)	4.71	4.15	5.41	5.14
2,680	(7)	8.50	8.61	10.23	8.68	2,433	(3)	8.99	8.09	2.73	5.50
2,681	(7)	5.73	5.19	5.02	6.05	2,434	(7)	N.S.	11.09	10.85	12.83
2,682	(7)	5.99	5.92	5.73	5.40	2,435	(7)	7.71	5.19	5.60	4.51
2,683	(6)	6.72	6.69	6.98	6.64	2,436	(7)	5.79	6.54	7.27	8.80
2,684	(7)	5.67	5.00	4.84	5.12	2,446	(8)	7.11	9.72	9.46	8.41
2,685	(7)	4.42	5.73	6.34	5.97	2,450	(8)	10.29	10.27	10.71	12.29
2,686	(7)	6.76	5.21	6.01	6.31	2,451	(8)	10.17	10.90	11.21	10.91
2,687	(6)	7.87	7.07	7.22	7.13	2,452	(8)	4.07	4.79	5.22	3.69
2,688	(6)	7.64	9.01	4.87	6.55	2,453	(8)	5.59	5.22	5.66	5.07
2,689	(6)	7.64	5.55	4.67	6.46	2,454	(10)	10.89	8.68	9.75	8.91
2,690	(7)	6.47	4.89	5.67	7.39	2,455	(8)	9.95	8.20	9.32	11.00
2,691	(1)	4.10	6.62	6.23	7.41	2,456	(8)	5.88	6.00	6.48	6.61
2,692	(6)	8.48	7.50	5.46	8.28	2,457	(8)	7.17	7.36	6.80	6.52
2,693	(7)	6.20	6.11	6.02	6.06	2,458	(8)	11.56	12.32	10.27	9.26
2,694	(7)	8.04	6.55	6.35	5.43	2,459	(3)	5.19	5.60	5.88	6.76
2,696	(7)	9.59	8.06	8.83	8.00	2,460	(7)	6.48	6.32	9.12	8.93
2,697	(7)	10.51	7.48	9.84	8.77	2,461	(1)	5.48	5.90	5.14	4.04
2,698	(7)	8.42	7.48	7.19	7.40	2,462	(1)	7.69	8.56	9.17	9.86
2,699	(7)	9.42	10.17	9.00	8.59	2,463	(2)	8.85	9.48	7.18	6.94
2,700	(7)	6.95	6.52	6.12	5.65	2,464	(2)	6.21	6.78	10.13	8.11
2,717	(7)	8.37	6.83	9.00	7.32	2,465	(6)	10.93	14.33	10.74	10.51
2,718	(7)	7.56	5.28	5.63	6.96	2,466	(7)	7.96	11.42	9.51	10.71
2,719	(3)	8.18	7.40	7.97	8.03	2,660	(7)	9.21	7.88	8.15	7.83
2,720	(3)	9.17	7.02	8.94	9.66	2,661	(3)	8.02	6.00	7.26	7.47
.....	.....	.....	.....	.....	.....	2,662	(6) and (8)	6.42	5.66	6.95	9.34
1½-Ton G. M. C. Trucks						**1½-Ton G. M. C. Trucks**					
3,033	(7)	8.55	5.81	5.97	6.13	4,304	(6)	6.56	4.22	5.85	7.21
4,303	(9)	9.01	5.71	5.29	8.70	4,309	(8)	5.86	5.44	4.21	4.84
4,311	(3)	6.73	7.30	5.84	5.38	4,314	(8)	7.77	5.31	5.85	8.13
4,315	(8)	6.21	4.11	8.11	6.09	4,317	(3)	4.49	4.77	6.16	5.79
4,318	(8)	3.41	3.14	3.12	3.16	4,319	(6)	6.33	5.74	6.93	8.38
4,321	(8)	3.62	4.12	3.60	4.53	4,330	(8)	4.72	5.40	5.84	6.32
4,437	(3)	6.33	N.S.	N.S.	N.S.	4,851	(8)	5.21	5.53	6.61	4.32
4,440	(3)	6.00	4.00	N.S.	N.S.	4,853	(8)	3.74	4.01	3.96	4.67
4,442	(8)	6.03	4.03	4.46	4.57	4,855	(8)	5.05	6.55	4.63	5.14
4,852	(8)	4.00	3.92	4.84	4.67	4,857	(8)	5.24	5.04	4.58	4.18
4,854	(8)	3.88	5.29	5.46	5.25	5,011	(8)	4.43	6.26	6.12	4.94
4,856	(8)	7.15	6.32	6.16	6.93	5,013	(8)	4.79	5.22	5.80	5.08
4,858	(8)	2.66	4.33	4.32	3.55	5,015	(8)	4.03	3.62	3.23	3.96
5,012	(10)	3.95	3.11	4.00	4.68	5,017	(8)	6.74	5.27	5.99	8.44
5,014	(8)	6.60	4.89	4.19	4.63	S-402	(4)	3.92	6.99	6.34	8.62
5,016	(3)	6.10	5.57	9.67	4.29	.....	.....	.....	.....	.....	.....
3-Ton Packard Trucks						**3-Ton Packard Trucks**					
6,168	(8)	2.34	2.53	4.83	2.67	6,169	(8)	3.19	2.84	3.16	4.70
6,301	(8)	2.77	4.75	2.90	3.59	6,302	(8)	3.04	5.18	3.39	5.06
6,303	(8)	3.77	3.97	3.32	3.11	6,420	(8)	3.47	3.46	3.09	3.11
6,421	(8)	3.13	3.06	3.88	3.80	6,422	(8)	3.29	3.02	3.16	3.47
6,423	(8)	2.86	2.86	2.60	2.70	6,424	(8)	5.02	3.35	1.94	2.75
6,425	(8)	2.61	2.64	2.61	2.31	6,493	(3)	4.00	N.S.	.....	4.35
6,495	(8)	3.03	3.54	2.52	3.03	.....	.....	.....	.....	.....	.....

[2] See p. 345 for explanatory notes.

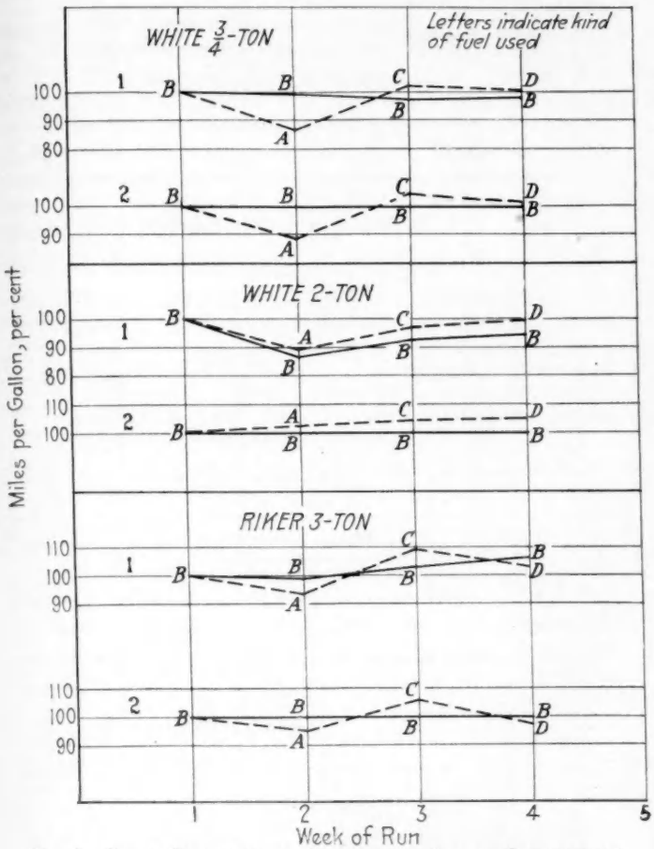

FIG. 2—CHART SHOWING THE MILEAGE PER GALLON OBTAINED AT PITTSBURGH WITH DIFFERENT MAKES OF VEHICLE

decided that, for comparative purposes, the same four fuels should be used in this test as were to be used in the Society of Automotive Engineers' Cooperative Fuel Tests. These fuels are styled Grades *A*, *B*, *C* and *D*. Grade-*B* fuel represents the average commercial gasoline on the market at present, and is used as a comparative or reference fuel. Grade-*A* fuel is of higher volatility, or lower end-point. Grades-*C* and *D* fuels represent lower volatility and higher end-point in the order of their alphabetical designation.

The average distillation-curves for the fuels used are shown in Fig. 1. Compared to Grade-*B* fuel, these fuels represent the average production per barrel of crude oil shown in Table 2.

In testing these fuels the following relative information was sought:

(1) Miles per gallon compared to Grade-*B* fuel

(2) Crankcase dilution in the engines run on these fuels as compared to dilution using Grade-*B* fuel

(3) Performance in service, particularly as to starting of engines, idling and general operation

TEST PROCEDURE

The following methods of test were used: The transportation units in Pittsburgh and in Philadelphia were each divided into two equal parts or sections designated as Section No. 1 and Section No. 2. In dividing the units, one-half of the total number of each make of truck was placed in each section. This method gave two sections equal in respect to the number of vehicles as well as to the capacities and makes.

One section of the fleet was at all times operated on Grade-*B* fuel in order that differences due to changes in weather conditions might be noted and allowed for in the final comparisons. Each truck in Section No. 1 was designated by the numeral 1, placed in some convenient place to be recognized by the truck dispatcher and the men putting fuel into the tanks. The same method was applied to Section No. 2, where the numeral 2 was placed.

From each section, three trucks of each make were

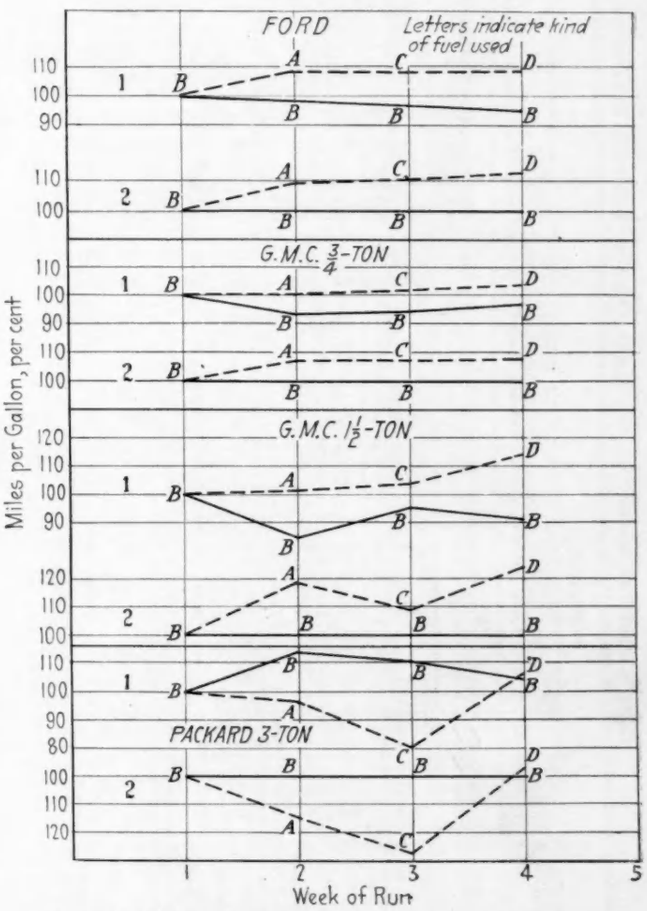

FIG. 3—CHART SHOWING THE MILEAGE PER GALLON OBTAINED AT PHILADELPHIA WITH DIFFERENT MAKES OF VEHICLE

EXPLANATORY NOTES FOR TABLE 3

(1) *Pouch Service*—Carrying pouches of first-class, special and registered mail, from the Central Post Office to and from the various sub-stations. The trucks are handicapped by the congested conditions in the alleyway at the Central Post Office.
(2) *Package-Box Collections*—Collection of mail from package boxes.
(3) *Reserve*—Extra cars placed in service when regular trucks are disabled or when the volume of mail to be transported is excessive.
(4) *Service Car*—Stationed at the Central Post Office for truck repair there; responds to service calls also.
(5) *Letter-Box Collection*—Collecting mail from letter-boxes.
(6) *Interstation*—Carrying mail between the Central Post Office and sub-stations; same handicap as for (1).
(7) *Parcel Post*—Delivery of parcel-post mail.
(8) *Screen-Wagon*—Hauling mail between the Central Post Office and the railroad depot; same handicap as for (1).
(9) *Equipment and Repair Truck*—Used for repairing letter-boxes, box-posts and the like.
(10) *Registry Truck*—Hauls registered mail between the Central Post Office and the Pennsylvania Railroad depot.
(11) *Registry Car*—Hauls registered mail to the banks.
(12) *Truck Supervision.*

TABLE 4—INDIVIDUAL-VEHICLE AND FLEET AVERAGES FOR FUEL CONSUMPTION

		Philadelphia Fleet										Pittsburgh Fleet								Average for Both Fleets	
		Ford		¾-Ton G.M.C. Truck		1½-Ton G.M.C. Truck		3-Ton Packard Truck		Fleet Average		¾-Ton White Truck		2-Ton White Truck		2-Ton Riker Truck		Fleet Average			
		Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2	Section No. 1	Section No. 2
First Week	Grade of Fuel	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
	Fuel Consumption, miles per gal.	9.31	9.97	7.71	7.74	5.64	5.26	2.92	3.66	7.22	7.50	5.61	5.81	5.34	4.77	2.37	2.46	4.89	4.78	6.53	6.65
	Correction for Condition of Fleet, per cent.	.....	−6.7	.....	−0.3	.....	+7.2	.....	−20.2	.....	−3.8	.....	−3.4	.....	+12.0	.....	−3.7	.....	+3.3	.....	−1.8
Second Week	Grade of Fuel	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
	Fuel Consumption, miles per gal.	9.17	10.78	7.21	7.78	4.77	5.29	3.34	3.57	6.86	7.76	5.57	5.09	4.68	4.27	2.33	2.31	4.72	4.29	6.21	6.71
	Correction for Condition of Fleet, per cent.	.....	10.06	.....	7.75	.....	5.67	.....	2.85	.....	7.48	.....	4.91	.....	4.78	.....	2.23	.....	4.39	.....	6.59
	Adjusted Values to First-Week Basis	9.31	10.23	7.71	8.29	5.64	6.70	2.92	2.49	7.22	7.88	5.61	4.94	5.34	5.46	2.37	2.27	4.89	4.55	6.53	6.93
	Change in Mileage, Grade *B* to Grade-*A* Fuel, per cent.	.....	+9.8	.....	+7.5	.....	+13.8	.....	−14.7	.....	+9.0	.....	−12.0	.....	+2.2	.....	−4.2	.....	−7.0	.....	+6.1
Third Week	Grade of Fuel	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
	Fuel Consumption, miles per gal.	8.98	10.77	7.29	7.89	5.36	5.47	3.24	2.95	6.95	7.78	5.43	5.88	4.92	4.61	2.44	2.69	4.72	4.86	6.27	6.84
	Correction for Condition of Fleet, per cent.	.....	10.05	.....	7.86	.....	5.86	.....	2.36	.....	7.49	.....	5.67	.....	5.16	.....	2.59	.....	4.97	.....	6.72
	Adjusted Values to First-Week Basis	9.31	10.41	7.71	8.31	5.64	6.16	2.92	2.13	7.22	7.78	5.61	5.86	5.34	5.60	2.37	2.52	4.89	5.15	6.53	7.00
	Change in Mileage, Grade *B* to Grade-*C* Fuel, per cent.	.....	+11.8	.....	+7.7	.....	+9.3	.....	−27.1	.....	+7.7	.....	+4.3	.....	+4.8	.....	+6.1	.....	+5.2	.....	+7.1
Fourth Week	Grade of Fuel	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D
	Fuel Consumption, miles per gal.	8.85	10.81	7.44	8.03	5.18	6.00	3.07	3.90	6.95	7.97	5.51	5.81	5.04	4.75	2.51	2.55	4.83	4.82	6.29	6.79
	Correction for Condition of Fleet, per cent.	.....	10.09	.....	8.00	.....	6.43	.....	3.11	.....	7.68	.....	5.61	.....	5.32	.....	2.46	.....	4.93	.....	6.67
	Adjusted Values to First-Week Basis	9.31	10.61	7.71	8.29	5.64	7.00	2.92	2.96	7.22	7.98	5.61	5.71	5.34	5.64	2.37	2.32	4.89	4.99	6.53	6.92
	Change in Mileage, Grade *B* to Grade-*D* Fuel, per cent.	.....	+13.9	.....	+7.5	.....	+23.1	.....	+1.3	.....	+10.5	.....	+1.8	.....	+5.6	.....	−1.9	.....	+2.1	.....	+6.0

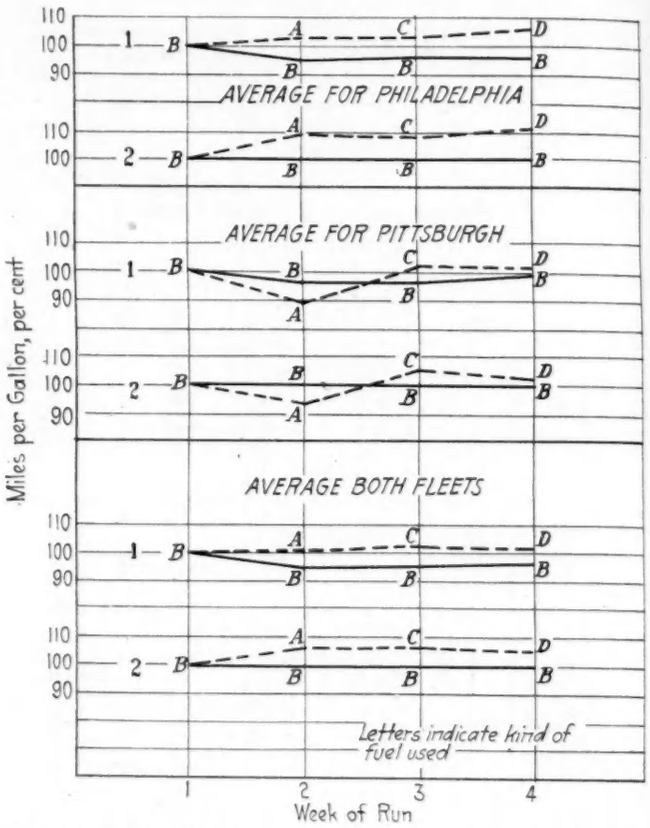

FIG. 4—AVERAGE MILEAGE PER GALLON OF FUEL FOR EACH WEEK OF THE TEST AT PHILADELPHIA AND PITTSBURGH AND THE GENERAL AVERAGE FOR BOTH FLEETS

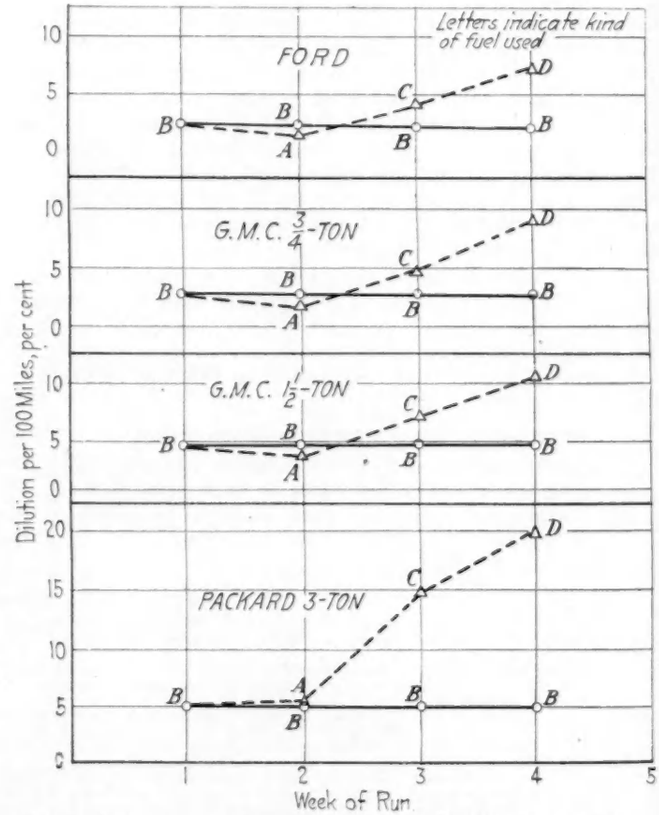

FIG. 5—CHART OF THE CRANKCASE DILUTION OF THE TRUCKS TESTED AT PHILADELPHIA

selected; the crankcases were drained of used oil and new oil was put in each week or period of the test. At the end of each run or each week a 1-qt. sample was drained from each engine thus selected and labeled as to the truck number, the make, the kind of fuel and the mileage. Each truck was labeled with the letter corresponding to the kind of fuel on which it was operating. This letter was placed in such a manner that mistakes were unlikely in placing the proper fuel in the tank.

The schedule of test was as follows:

First Week—Both sections were run on Grade-*B* fuel. All trucks were drained, the fuel was placed in the tank and the mileage was noted. At the end of the week the fuel remaining in the tanks was drained and measured, and this amount was deducted from the total fuel put into the tanks during the run. The mileage was noted at the end of a run

Second Week—Section No. 1 continued on Grade-*B* fuel and Section No. 2 was run on Grade-*A* fuel; the same procedure was followed as for the first week.

Third Week—Section No. 1 continued on Grade-*B* fuel and Section No. 2 was run on Grade-*C* fuel, following the same procedure as in the two previous runs

Fourth Week—Section No. 1 was again continued on Grade-*B* fuel, and Section No. 2 was run on Grade-*D* fuel, following the same procedure as in the preceding weeks

As each shipment of fuel was placed in the supply tanks, a 1-gal. sample was taken and labeled as to the date and the kind of fuel. Distillations were run on these samples to check the fuel delivered by the refinery. All samples were shipped to the Bureau of Standards at the City of Washington, where the laboratory tests were made

Table 3 gives the individual truck averages for each week of the four-week runs. A wide variation will be noted in miles per gallon for trucks of the same make, which may be explained by differences in the engine condition and adjustment, the type of service and the

TABLE 5—MISCELLANEOUS DATA ON OIL USED

Period	Philadelphia Samples													
	Kind of Oil	Make of Truck	Truck No.	Number of Miles	Grade of Fuel	Section No.	Initial Point		Percentage Distilled at 300 Deg. Cent. (572 Deg. Fahr.)	Gravity		Viscosity at 100 Deg. Fahr., Saybolt Sec.	Flash-Point, Deg. Fahr.	Fire-Test, Deg. Fahr.
							Deg. Cent.	Deg. Fahr.		Specific	Baume			
First Week	New Medium	....	....	....	....	....	(a)300	(a)572.0	.....	0.906	24.5	316	415	475
	Used Medium	Ford	850	143	*B*	1	163	325.4	5.0	0.905	24.7	293	285	440
			512	244	*B*	1	165	329.0	6.0	0.900	25.6	280	240	390
			513	349	*B*	1	182	359.6	4.0	0.902	25.2	298	315	435
			1,711	308	*B*	2	185	365.0	3.5	0.904	24.9	320	315	450
			1,708	350	*B*	2	168	334.4	4.0	0.902	25.2	294	325	440
			1,710	253	*B*	2	180	356.0	4.5	0.902	25.2	299	305	410
		¾-Ton G.M.C.	2,691	127	*B*	1	171	339.8	6.5	0.900	25.6	242	255	245
			2,679	284	*B*	1	178	352.4	7.0	0.899	25.7	247	235	345
			2,692	352	*B*	1	188	370.4	11.0	0.895	26.4	170	(b)	(b)
			2,463	433	*B*	2	180	356.0	9.5	0.898	25.9	208	215	360
			2,466	225	*B*	2	179	354.2	7.5	0.902	25.2	258	225	445
			2,458	352	*B*	2	148	298.4	9.0	0.899	25.7	203	210	415
	New Heavy	....	....	....	....	....	300	572.0	.....	0.931	20.4	486	430	500
	Used Heavy	1½-Ton G.M.C.	4,318	109	*B*	1	165	329.0	8.0	0.898	25.9	249	215	345
			3,033	201	*B*	1	175	347.0	8.0	0.899	25.7	234	210	320
			4,858	145	*B*	1	168	334.4	4.0	0.901	25.4	315	275	435
			4,304	240	*B*	2	148	298.4	11.0	0.893	26.8	167	175	255
			4,851	213	*B*	2	160	320.0	7.0	0.898	25.9	230	230	370
			4,319	242	*B*	2	135	275.0	5.5	0.900	25.6	247	210	410
		3-Ton Packard	6,425	141	*B*	1	170	338.0	6.5	0.898	25.9	200	215	360
			6,303	130	*B*	1	173	343.4	8.5	0.898	25.9	260	210	320
			6,168	114	*B*	1	176	348.8	3.5	0.901	25.4	265	235	415
			6,302	129	*B*	2	155	311.0	3.5	0.902	25.2	326	240	455
			6,169	136	*B*	2	150	302.0	14.5	0.890	27.3	153	130	185
			6,434	197	*B*	2	158	316.4	8.0	0.900	25.6	284	195	330
Second Week	New Medium	....	....	....	....	....	(a)300	(a)572.0	.....	0.906	24.5	316	415	475
	Used Medium	Ford	513	355	*B*	1	175	347.0	3.0	0.900	25.5	266	320	455
			512	245	*B*	1	150	302.0	7.5	0.898	25.9	212	220	375
			850	217	*B*	1	170	338.0	8.0	0.897	26.0	211	225	405
			1,710	311	*A*	2	152	305.6	4.5	0.903	25.0	300	270	450
			1,711	287	*A*	2	156	312.8	3.0	0.903	25.0	303	335	475
			1,708	357	*A*	2	167	332.6	2.5	0.902	25.2	294	255	450
		¾-Ton G.M.C.	2,679	282	*B*	1	162	323.6	8.5	0.897	26.1	206	205	350
			2,691	139	*B*	1	175	347.0	5.5	0.900	25.5	240	255	400
			2,692	352	*B*	1	160	320.0	11.0	0.893	26.7	181	200	285
			2,463	417	*A*	2	156	312.8	7.5	0.897	26.1	210	205	395
			2,466	191	*A*	2	130	266.0	6.0	0.899	25.7	238	225	410
			2,458	355	*A*	2	150	302.0	7.0	0.897	26.1	221	205	430
	New Heavy	....	....	....	....	....	....	....	.....	0.931	20.4	486	430	500
	Used Heavy	1½-Ton G.M.C.	3,033	186	*B*	1	....	....	8.5	0.897	26.1	231	185	350
			4,858	145	*B*	1	168	334.4	4.0	0.900	25.6	279	230	450
			4,318	113	*B*	1	163	325.4	7.0	0.898	25.9	233	210	350
			4,304	227	*A*	2	155	311.0	8.0	0.898	25.9	194	185	335
			4,851	36	*A*	2	160	320.0	2.5	0.892	26.9	268	265	460
			4,319	241	*A*	2	135	275.0	4.5	0.899	25.7	243	210	455
		3-Ton Packard	6,303	119	*B*	1	157	314.6	4.5	0.901	25.4	253	230	455
			6,425	116	*B*	1	150	302.0	5.0	0.898	25.9	207	210	415
			6,168	96	*B*	1	157	314.6	4.0	0.901	25.4	254	240	455
			6,424	137	*A*	2	148	298.4	5.5	0.898	25.9	225	200	405
			6,169	129	*A*	2	145	293.0	13.0	0.888	27.7	123	145	190
			6,302	156	*A*	2	152	305.6	3.0	0.901	25.4	255	230	460

(a) Temperature of 5-per cent distillation, 370 deg. cent (698 deg. fahr.)
(b) Insufficient amount of oil.

operators. Table 3 also gives the duties of the trucks in Philadelphia. The low mileage on some of the trucks used in letter-box collection-service can be understood better when it is realized that these trucks make an average of some 300 stops in the course of an 8-hr. tour of duty. The trucks in Pittsburgh are required to perform service similar to that of those in Philadelphia, except that the ¾-ton White trucks used in Pittsburgh for letter-box collection-service do not make as many stops in a tour of duty as do the Fords in Philadelphia. Table 4 gives the averages of individual trucks in both fleets, compared with Grade-*B* fuel.

It will be noted that a slightly higher mileage was obtained with the less volatile fuels. This can be explained by the fact that, as the volatility is decreased, the viscosity of the fuel increases and therefore, with a fixed carbureter-setting, slightly less fuel will pass through the carbureter jets and a leaner mixture will result. The difference in mileage therefore is due to a change in the mixture-ratio rather than in the fuel volatility.

The curves in Figs. 2, 3 and 4 give the individual averages of trucks in both cities and the average for both fleets. Curve No. 1 for each make of vehicle shows the actual percentage of change before any correction has been made for the change in the operation on Grade-*B* fuel. Curve No. 2 shows the results after correcting.

A study of these results will show that it seems to make very little difference in the miles per gallon when a truck is operating on any one of the four fuels, under the warm-weather conditions that prevailed while this test was run, and within the range of accuracy possible in a test of this kind. Little or no trouble was experienced in operating on the various fuels, except for a slight difficulty in starting on the Grade-*D* fuel and the necessity of more throttle-opening for proper idling.

Method of Examining Oil Samples

The following procedure was followed when testing used-oil samples for the percentage of dilution. The initial-point of the new oil was ascertained at atmospheric

TABLE 5—MISCELLANEOUS DATA ON OIL USED—*Concluded*

Period	Kind of Oil	Make of Truck	Truck No.	Number of Miles	Grade of Fuel	Section No.	Initial Point		Percentage Distilled at 300 Deg. Cent. (572 Deg. Fahr.)	Gravity		Viscosity at 100 Deg. Fahr., Saybolt Sec.	Flash-Point, Deg. Fahr.	Fire-Test, Deg. Fahr.
							Deg. Cent.	Deg. Fahr.		Specific	Baume			
			Philadelphia Samples											
Third Week	Used Medium	Ford	850	177	*B*	1	(*c*)	.....	4.0	0.903	25.0	337	356	460
			512	245	*B*	1	168	334.4	6.5	0.899	25.7	171	230	400
			513	356	*B*	1	163	325.4	5.0	0.900	25.4	260	285	455
			1,711	287	*C*	2	186	366.8	6.0	0.901	25.3	248	280	410
			1,710	238	*C*	2	175	347.0	6.5	0.901	25.3	267	255	385
			1,708	407	*C*	2	190	374.0	6.0	0.901	25.3	241	270	400
		¾-Ton G.M.C.	2,692	362	*B*	1	152	305.6	8.5	0.898	25.9	210	200	390
			2,691	134	*B*	1	176	348.8	5.0	0.899	25.7	241	255	440
			2,679	278	*B*	1	167	332.6	5.0	0.899	25.7	267	255	435
			2,458	368	*C*	2	168	334.4	18.5	0.885	28.2	115	170	225
			2,463	412	*C*	2	170	338.0	17.0	0.890	27.2	134	190	235
			2,466	270	*C*	2	183	361.4	13.0	0.894	26.6	165	210	285
	Used Heavy	1½-Ton G.M.C.	3,033	200	*B*	1	....	.....	8.0	0.898	25.9	235	205	385
			4,318	103	*B*	1	150	302.0	7.5	0.897	26.0	259	185	300
			4,858	136	*B*	1	....	.....	3.5	0.901	25.4	293	270	445
			4,304	240	*C*	2	160	320.0	13.5	0.891	27.1	175	180	245
			4,319	245	*C*	2	160	320.0	9.0	0.898	25.9	209	210	340
			4,851	108	*C*	2	173	343.4	6.5	0.898	26.2	230	230	400
		3-Ton Packard	6,303	123	*B*	1	151	303.8	4.0	0.901	25.4	314	230	475
			6,425	115	*B*	1	147	296.6	4.5	0.899	25.7	255	215	235
			6,168	140	*B*	1	164	327.2	4.0	0.901	25.4	315	225	455
			6,424	69	*C*	2	170	338.0	9.0	0.894	26.6	178	195	285
			6,169	143	*C*	2	155	311.0	30.0	0.871	30.7	77	140	175
			6,302	145	*C*	2	172	341.6	6.5	0.899	25.7	248	220	445
Fourth Week	Used Medium	Ford	850	158	*B*	1	....	.....	3.0	0.907	24.3	339	345	465
			512	259	*B*	1	107	224.6	4.0	0.904	24.9	325	290	445
			513	294	*B*	1	187	368.6	2.5	0.903	25.0	306	375	455
			1,710	309	*D*	2	205	401.0	8.0	0.898	25.9	252	260	400
			1,711	287	*D*	2	205	401.0	6.5	0.900	25.5	261	280	395
			1,708	....	....	....	....	.....	.....	.....	....	....	....	....
		¾-Ton G.M.C.	2,679	249	*B*	1	175	347.0	4.0	0.902	25.2	306	260	435
			2,692	298	*B*	1	172	341.6	7.5	0.899	25.7	229	210	375
			2,691	122	*B*	1	....	.....	5.5	0.899	25.7	267	255	440
			2,463	378	*D*	2	185	365.0	30.5	0.876	29.8	84	180	205
			2,458	287	*D*	2	170	338.0	36.0	0.874	30.2	71	255	440
			2,466	182	*D*	2	....	.....	19.0	0.891	27.1	149	215	250
	Used Heavy	3-Ton Packard	6,425	83	*B*	1	....	.....	5.0	0.899	25.7	287	215	445
			6,168	131	*B*	1	174	345.2	4.0	0.901	25.4	333	245	480
			6,303	101	*B*	1	162	323.6	3.5	0.903	25.0	350	255	475
			6,302	119	*D*	2	178	352.4	6.0	0.898	25.9	272	220	385
			6,424	114	*D*	2	175	347.0	18.5	0.886	28.0	138	190	215
			6,169	127	*D*	2	160	320.0	31.0	0.872	30.5	82	145	190
		1½-Ton G.M.C.	4,858	117	*B*	1	174	345.2	3.0	0.902	25.2	330	275	460
			4,318	109	*B*	1	....	.....	6.5	0.900	25.5	285	220	450
			3,033	98	*B*	1	168	334.4	7.0	0.898	25.9	289	210	390
			4,304	202	*D*	2	180	356.0	18.8	0.896	26.2	143	185	235
			4,851	67	*D*	2	190	374.0	8.0	0.896	26.2	200	230	330
			4,319	201	*D*	2	185	365.0	9.0	0.896	26.2	140	215	335
			2,460		(*d*)		175	347.0	24.0	0.882	28.7	100	185	215

(*c*) Contained water.
(*d*) Four-week run, with four fuels.

pressure, using a 100-cc. sample in an Engler flask with a water-cooled condensation apparatus. Employing the same apparatus with the used oil, the percentage distilled over at the initial-point of the new oil was noted. This was termed the percentage of dilution. To check this method, samples of new oil were diluted with known percentages of the distillates from the used oil and distillations run on these samples. The results obtained agreed with the known percentage of dilution.

Following the method outlined, the results obtained for the percentage of dilution from the several trucks operating on the different fuels are shown in Tables 5 and 6. Used-oil samples were also examined for changes in viscosity, specific gravity, flash-point and fire-test; the results are shown in Tables 5 and 6 also. The curves in Figs. 5 and 6 show relative crankcase dilution per 100 miles for the four fuels. The curves in Fig. 7 give the fleet averages for both Philadelphia and Pittsburgh. In considering the average dilution for both fleets, it will be noted that, compared with the trucks run on Grade-*B* fuel, those run on Grade-*A* fuel had less crankcase-oil dilution, and that Grades *C* and *D* gave correspondingly more crankcase-oil dilution. From these values the curves shown in Fig. 8 were plotted for

TABLE 6—MISCELLANEOUS DATA ON OIL USED

Pittsburgh Samples

Kind of Oil	Make of Truck	Truck No.	Number of Miles	Grade of Fuel	Section No.	Initial Point		Percentage Distilled at 300 Deg. Cent. (572 Deg. Fahr.)	Gravity		Viscosity at 100 Deg. Fahr., Saybolt Sec.	Flash-Point, Deg. Fahr.	Fire-Test, Deg. Fahr.
						Deg. Cent.	Deg. Fahr.		Specific	Baume			
New Heavy						300	572.0	.....	0.904	24.9	486	430	500
Used Heavy	¾-Ton White	2,114	360	*A*	2	134	273.2	8.0	0.898	25.9	292	180	350
			360	*B*	2	153	307.4	10.0	0.896	26.2	260	170	295
			360	*C*	2	....	.....	10.0	0.897	26.1	200	190	300
			300	*D*	2	165	329.0	4.0	0.902	21.8	333	220	390
		2,106	306	*A*	2	146	294.8	4.5	0.902	25.2	308	205	445
			255	*B*	2	160	320.0	8.0	0.899	25.7	317	190	385
			306	*C*	2	175	347.0	8.0	0.901	25.4	313	210	385
			296	*D*	2	170	338.0	9.5	0.897	26.1	278	115	265
		2,236	210	*A*	2	138	280.4	22.0	0.886	28.0	118	125	160
			180	*B*	2	140	240.0	23.5	0.879	29.3	104	130	185
			190	*C*	2	134	273.2	36.5	0.869	31.1	80	130	165
			170	*D*	2	135	275.0	21.5	0.904	24.9	123	155	200
		2,113	204	*B*	1	144	291.2	9.5	0.897	26.1	256	165	450
			170	*B*	1	130	266.0	9.5	0.896	26.2	261	185	335
			170	*B*	1	140	284.0	7.5	0.898	25.9	284	190	375
			183	*B*	1	132	269.6	10.0	0.895	26.4	246	180	275
		2,105	363	*B*	1	163	325.4	7.0	0.904	24.9	441	255	480
			240	*B*	1	154	309.2	5.0	0.903	25.0	419	250	300
			288	*B*	1	150	302.0	6.5	0.901	25.4	366	230	470
			240	*B*	1	....	.....	6.0	0.902	25.2	390	250	445
		2,705	350	*B*	1	....	.....	12.0	0.891	27.1	214	195	240
			280	*B*	1	....	.....	13.0	0.891	27.1	192	160	220
			341	*B*	1	160	320.0	9.0	0.897	26.1	286	185	310
			393	*B*	1	147	296.6	14.5	0.889	27.5	176	160	200
Used Heavy	2-Ton White	4,868	226	*A*	2	143	289.4	7.5	0.899	25.7	280	175	300
			190	*B*	2	152	305.6	8.5	0.899	25.7	289	185	310
			228	*C*	2	160	320.0	11.0	0.895	26.4	234	180	275
			228	*D*	2	....	.....	15.0	0.891	27.1	186	170	220
		4,878	90	*A*	2	152	305.6	4.5	0.902	25.2	384	230	505
			90	*B*	2	162	323.6	5.0	0.902	25.2	407	170	360
			90	*C*	2	178	352.4	5.5	0.901	26.9	354	225	410
			94	*D*	2	....	.....	6.0	0.899	25.7	338	235	400
		4,876	114	*A*	2	148	298.4	7.0	0.892	26.9	208	180	245
			114	*B*	2	150	302.0	9.0	0.898	25.9	251	190	350
			114	*C*	2	170	338.0	11.5	0.898	25.9	273	170	360
			114	*D*	2	156	312.8	7.0	0.898	25.9	273	220	345
		4,881	246	*B*	1	....	.....	6.5	0.901	26.9	344	220	405
			205	*B*	1	....	.....	4.0	0.903	15.0	436	230	465
			246	*B*	1	160	320.0	6.0	0.901	26.9	367	210	420
			246	*B*	1	167	332.6	3.5	0.903	25.0	453	255	440
		4,867	208	*B*	1	165	329.0	8.5	0.898	25.9	275	185	445
			228	*B*	1	162	323.6	8.5	0.897	26.1	257	180	280
			228	*B*	1	....	.....	6.0	0.899	25.7	310	200	345
		4,873	226	*B*	1	163	325.4	9.0	0.896	26.2	262	185	340
			451	*B*	1	167	332.6	8.5	0.898	25.9	366	180	315
			468	*B*	1	165	329.0	4.5	0.903	25.0	424	235	445
			451	*B*	1	168	334.4	11.0	0.895	26.4	261	185	275
			407	*R*	1	156	312.8	5.5	0.901	26.9	388	210	460
Used Heavy	3-Ton Riker	6,470	170	*A*	2	138	280.4	9.0	0.894	26.6	247	165	350
			188	*B*	2	....	.....	26.0	0.877	29.6	93	180	210
			182	*C*	2	164	327.2	12.0	0.891	27.1	204	170	205
			78	*D*	2	152	305.6	9.5	0.894	26.6	238	175	285
		6,472	108	*A*	2	158	316.4	11.0	0.894	26.6	214	175	245
			81	*B*	2	163	325.4	13.0	0.894	26.6	198	170	215
			97	*C*	2	173	343.4	8.0	0.896	26.2	263	205	400
			114	*D*	2	166	330.8	13.0	0.891	27.1	190	185	225
		6,484	88	*A*	2	145	293.0	10.0	0.893	26.8	209	145	275
			98	*B*	2	....	.....	13.0	0.890	27.3	173	170	195
			90	*C*	2	160	320.0	14.0	0.899	25.7	170	150	215
			88	*D*	2	155	311.0	15.5	0.885	28.2	143	155	195
		6,481	117	*B*	1	150	302.0	12.0	0.891	27.1	190	165	220
			112	*B*	1	143	289.4	20.0	0.883	28.5	142	135	185
			100	*B*	1	127	260.6	12.5	0.891	27.1	185	170	195
			114	*B*	1	(*e*)	.....	18.5	0.882	28.7	128	140	170
		6,485	74	*B*	1	160	320.0	13.0	0.890	27.3	187	190	230
			118	*B*	1	160	320.0	13.5	0.889	27.5	174	160	190
			126	*B*	1	160	320.0	13.0	0.888	27.6	184	170	220
			184	*B*	1	158	316.4	13.5	0.891	27.1	197	120	215
			212	*B*	1	152	305.6	15.5	0.886	28.0	156	145	195
		6,475	199	*B*	1	158	316.4	15.0	0.889	27.5	160	160	185
			202	*B*	1	155	311.0	17.0	0.886	28.0	145	145	170
			169	*B*	1	160	320.0	11.0	0.893	26.8	202	170	250

(*e*) Considerable water.

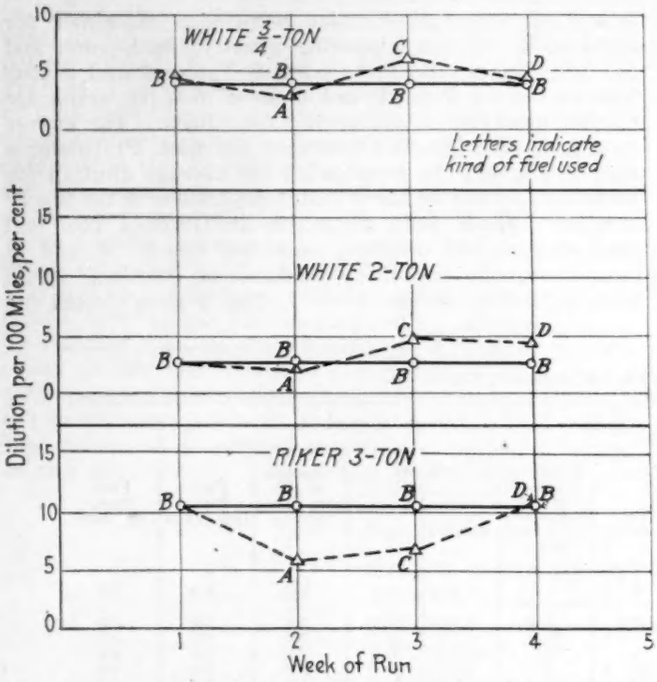

FIG. 6—CHART OF THE CRANKCASE DILUTION OF THE TRUCKS TESTED AT PITTSBURGH

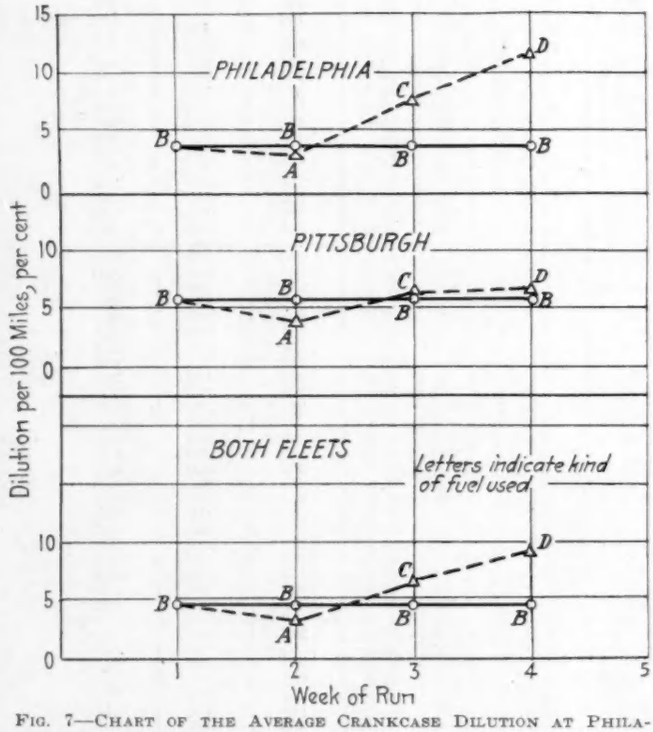

FIG. 7—CHART OF THE AVERAGE CRANKCASE DILUTION AT PHILADELPHIA AND PITTSBURGH AND THE GENERAL AVERAGE FOR BOTH FLEETS

the percentage of dilution against the temperature from the distillation curves of the 85 and 95-per cent points. The curves show that, as the end-point of the fuel is increased, the dilution of the oil is materially increased.

To compare the change in viscosity and specific gravity due to dilution, samples of new oil were diluted with the distillates from used oils to the following percentages: 5, 10, 15, 20, 25, 30, 35 and 40 per cent. These samples were then examined for viscosity and specific gravity. The results are shown in the curves of Fig. 9. The points in the small circles represent the changes noted in the viscosity and the specific gravity of used oils of known percentage of dilution.

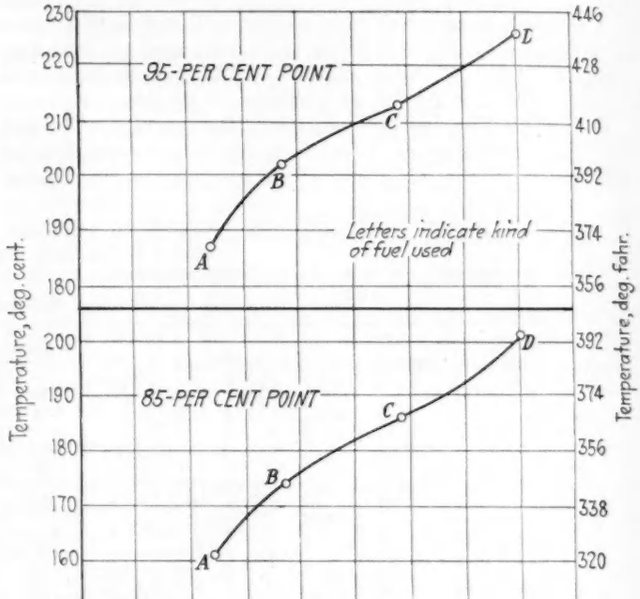
95-PER CENT POINT
85-PER CENT POINT
Letters indicate kind of fuel used
Temperature, deg. cent.
Temperature, deg. fahr.
Dilution per 100 Miles, per cent

FIG. 8—CURVES SHOWING THE RELATION BETWEEN THE PERCENTAGE OF DILUTION PER 100 MILES AND THE TEMPERATURES OF THE 85 AND 95-PER CENT DISTILLATION POINTS

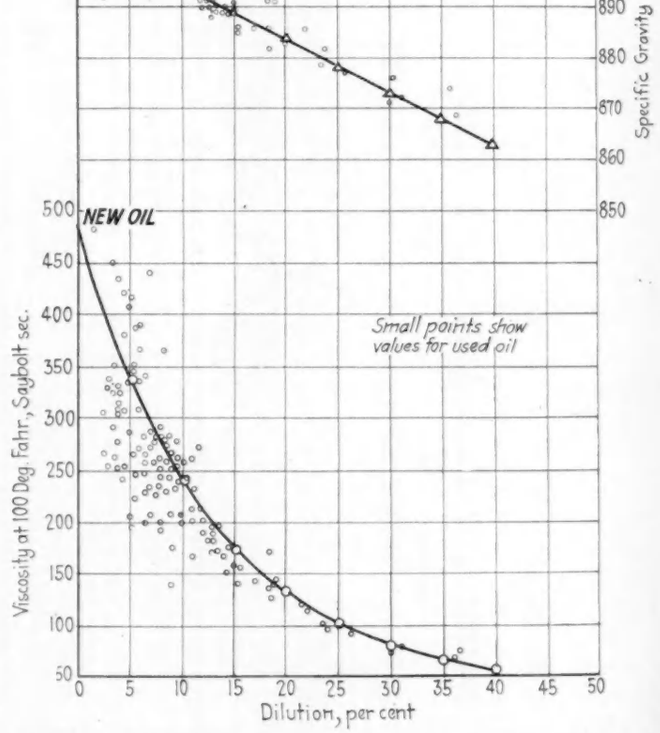

FIG. 9—CURVES SHOWING HOW THE VISCOSITY AND THE SPECIFIC GRAVITY OF THE NEW LUBRICATING OIL CHANGED WHEN DILUTED WITH VARYING PERCENTAGES OF DISTILLATES FROM THE USED OIL

Vol. XII April, 1923 No. 4

Passenger-Carrying Flying-Boat Operation

By H. A. Bruno[1]

Annual Meeting Paper

THE author states that commercial aviation is an accomplished fact as proved by the successful operation of the flying-boats he represents, and cites performance-records in proof. He finds it most difficult to convince the public that flying is safe.

The different types of flying boat in use are mentioned and the author discourses in regard to influencing the public to fly, citing the successful 90-min. flying-boat service between Cleveland and Detroit, and the other similar successful services, as inducements. He concludes with a plea that all who are interested in the success of commercial aviation support its pioneers.

WE have found that the existing type of flying-boat is capable of taking care of the demand of today. I have often heard engineers say that the moment we design a machine capable of carrying 15 to 20 passengers at reduced rates, we will have commercial aviation in this Country. We have commercial aviation here today. Time and time again we read of what they have done in Europe but, when it comes to over-water air-transportation, we are ahead of Europe. To quote from an editorial:

> Anybody may steal a safety device. We await a genius with some miraculous invention that will make flying safe. Meanwhile, one of America's leading commercial flying companies is using a very old device with brilliant success. There are no patents on it. Its cost is low. The name of it is carefulness.
>
> The annual report of a company that operates 27 flying-boats says that during the last year it has made 2125 flights and carried 9107 passengers, a total of 739,047 passenger-miles. This has been done without a single death or injury. Carefulness in inspections, in operation and in selecting men has produced a perfect safety-record for 3 consecutive years.

Again, in a recent issue of the *United States Air-Service Magazine*, we read:

> The record is 3 years of service without a single mishap; this is unparalleled in the history of aeronautics or any other method of transportation.

The record referred to is that of the Aeromarine Airways and has been made with flying-boats supposed to be surplus war-material. The types we have used are the F5L and the HS2. These were converted by building an enclosed cabin on the F5L and converting the HS2 into an open-cockpit boat.

Inducing the Public to Fly

We have found that the actual cost of operating these flying-boats, in regard to gasoline, oil, maintenance and depreciation, is as nothing when compared to the cost of selling aviation to the public and getting passengers down to an airport to fly. It is disheartening to go to a man of more than ordinary intelligence and beg him to go on a free flight; he will say "I prefer to keep one foot on the ground." That condition exists solely through ignorance. But thinking men and women usually see the light when they are presented with statistics showing that flying is safe; and it is safe.

We have an unfortunate situation here in that we are one of the few countries in the world that has no air-laws. We believe that defect will be remedied very shortly. In the meantime, we are not waiting for those air-laws. A few pioneers are going ahead and putting commercial aviation in America ahead of that of the rest of the world. Again I am speaking of flying-boats only.

If engineers designed a flying-boat which would go twice as fast as these we are operating, and our operating expense were cut 50 per cent, that would not help us to sell aviation to the public. The cost of getting the public to fly is the important thing. Many times people have told me that they have heard in general discussion that aircraft in America today are unsafe to fly in. Granted that many of them are unsafe when operated by irresponsible fliers, there are a few responsible companies operating good machines. We must let the public know in every way possible that we have commercial aviation now; not "when it comes" and "when we have a certain safe type of ship." We are flying safely now, every day.

The public does not want speed. The average speed of our flying-boats is from 65 to 90 m.p.h. That is enough for anybody. If you tell a man that you will fly him from New York City to Albany at 125 m.p.h., the chances are that he would not fly with you. The thought amazes him; he cannot comprehend flying at that speed. We know that a passenger is perfectly happy and comfortable in an enclosed cabin, even at 135 m.p.h., but the man in the street does not realize that. We who are engaged in commercial aviation are so "sold" on it ourselves that we do not get the viewpoint of the man in the street.

As stated, the general design of flying-boats is satisfactory today. I am referring to the F5L, the HS2, the two-passenger Curtiss Seagull and Aeromarine model 40. They will take care of the public demand, I believe, for the next 3 or 4 years. When the public is finally sold in general, it will be necessary to have 40 and 50-passenger ships. But it would be dangerous today to consider this possibility and not "boost" what we have already; because we would be wasting valuable time, Europe meantime going right ahead.

Influencing the Public

The public today is very easily influenced in regard to flying. We in the business can go to a man and tell him we would like him to fly and that it is wonderful to fly, with only slight effect. But if his neighbor goes to him and says, "I took a flight today," that creates the desire in his mind and he wants to fly. It is the human element. People do not want to be left behind. If some one else is doing a thing, we want to do it.

There is a great change in public sentiment as regards flying in this Country. We have noticed it in connection with railroads. When we started to operate flying-boats

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3 years ago the railroad representatives said, "Well, it may come true, we hope it will, but we are not interested and you are taking up our time." But the New York Central Railroad Co. sent out a bulletin recently instructing its ticket-agents to furnish information on our flying-boat transportation, stating it is worthy of support. Many other railroads have followed suit. The Florida East Coast Railway Co., which operates the steamers between Key West and Havana, is distributing our literature, because we have shown that properly operated commercial flying is absolutely safe and a necessary adjunct to the railroads; it is not a competitor, but an adjunct.

If you go into the travel department of any bank in a big city in the United States and inquire about our flying-boat service, I think you will find that it will try to get you to fly. Why? Because the banks realize that the development of commercial aviation is today and will be the backbone of our national defence.

I urge you to get behind the pioneers who are putting aviation over now. We are bucking a hard game but we see the clouds breaking. We are carrying more people every day, and are making money with the present equipment. In commercial operations during the past year our company made money between Cleveland and Detroit on a pioneer service. Our boats fly between Cleveland and Detroit in 90 min. The trip takes 6 hr. by train; all night by steamer. We flew more than 4000 people in 2½ months. The first month, 49 per cent were women and children; the second month the passengers were mostly business men. Many of them have said to us, "You have proved that commercial aviation is here and we are going to boost it." They are boosting American aviation and I ask you to do the same thing.

THE DISCUSSION

JOHN P. TARBOX:—The fundamental feature of commercial-aviation success has not yet been touched upon. Must we rely upon the necessities of the Post Office Department, upon the goodness of Uncle Sam in standing a loss and upon the sporting blood of the public to get this industry to grow? Or must we rely upon the basic fact that we can offer to the public a traffic which it can use at a profit? Does not the root of the present high cost of getting people to use an airplane lie in the fact that, while people use it for the sensation, they, having had the sensation, do not care to go to the expense of a second sensation? We are forced in our advertising constantly to convince new people. We are doing the same work again and again. The success of the Aeromarine Airways, Inc., between Cleveland and Detroit is probably the most signal success that has been had. Perhaps that from Key West to Havana is in the same class, but it seems that people are using flying-boats between Cleveland and Detroit because they find that they can do so in their business at a profit.

Commercial-airplane design lends possibilities of giving to the public just that basic thing. Must we wait all these years to put this proposition over, or can we hope to do it through a vastly improved engine? Judging from what has been said here, only a small percentage of increase in profit would be sufficient. Suppose we had an engine that would develop from 10 to 20 per cent more power. Suppose we had a wing that was from 10 to 20 per cent more efficient, or, if not more efficient, that would give us a lower landing-speed and enable us to utilize to a larger extent those fields that are now available. Suppose we had safety-devices that not only would neutralize what is left of the backwardness of the public in boarding aircraft, but also counteract the effect of the untoward accidents that have come through carelessness. The public patronizes the devices at the amusement parks, the shoot-the-chutes and the loop-the-loop affairs, without the least bit of hesitation. Why? Because the crowds are doing it and because it is not over-expensive. Airplane flying is no more dangerous than that. Suppose someone produced a material that would give us a greater factor of safety, or enable us to reduce the weight of the airplane and thereby increase the useful load 10 or 15 or 20 per cent. Any one of these things or a dozen others might put the proposition over. I urge that we all look toward the improvement of the individual units of the airplane in the hope that such improvement will lend its share to general advancement of the business.

CHAIRMAN E. P. WARNER:—I am surprised that so many of the speakers have found the present airplane wholly satisfactory and have been disposed to neglect the advisability of any change, at least for the present. I am even more surprised at Mr. Blythe's statements regarding the inconvenience of traveling by air and his disposition to neglect altogether the question of safety as seemingly unimportant. The record that the Aeromarine Airways, Inc., has made is wonderful and is certainly worthy of the very highest praise; 740,000 passenger-miles without a fatality! The average in Europe has been only about 400,000 passenger-miles, although there are several lines that have run very much farther than that, some going well over 1,000,000. American railroads have an average record of about 70,000,000 passenger-miles per fatality. We must make still greater improvements in the safety of airplanes before we can expect people to ride in large numbers.

From people who have flown once and been asked to fly again and declined, and those who have not even been asked but made it known that they would not fly if they were asked, I learn that the thing that keeps them from flying is not the inconvenience, which is often very slight; it is the danger, or what they think to be the danger. They badly over-estimate the danger, to be sure, but that is what keeps them on the ground. In the summer of 1922 I talked with a number of the agents who are backing air transportation in London and Paris and, judging from what I heard, very much the same story can be told there as in this Country. They say that as soon as there is a sensational accident anywhere, even to a military machine, the bookings fall right off dead. After one such accident, the London-to-Paris airplane bookings dropped off about 50 per cent in 3 weeks. Very often a person comes in and engages passage, and comes back in about 2 days and wants to cancel it. Such people have been talking to their friends, who have all bidden them a fond farewell; they give up the hazardous adventure. That is the thing that is keeping people from flying. As for the inconvenience, the London-to-Paris line sends a luxurious automobile around for you and lands you by car at your hotel on the other end.

MR. TARBOX:—I agree with Professor Warner in regard to the necessity of safety. I think it is of extreme importance. There is no question that flying is safe when carefully done, but there is a great amount of carelessness, and everything that can be done, through the application of safety devices, the enactment of laws and the enforcement of regulations, would be of immense help.

Has anything startling been done in great-altitude flying abroad? What instruments do they use for night-flying and for flying in fog?

CHAIRMAN WARNER:—There has been no great-altitude commercial-flying abroad. Navigation at night and in

fog is not attempted. They do not endeavor to fly under conditions such as those encountered by the Air-Mail Service in this Country. One line, operating across Central Europe, probably comes closer to it than any other I asked one pilot how he navigated in low clouds and fog. He said he flew below the clouds. I said, "If the clouds or fog are only 500 ft. above the earth, what do you do?" He said, "We still stay below them." I said, "Suppose they are only 100 ft. above the earth?" He said, "We still stay below them." I had not the courage to follow him down any farther. On another line, which operates with perhaps a little larger percentage of passenger traffic, they did not attempt to go out if the report showed clouds lower than 1000 ft. high above any part of the course to be followed. As for night-flying, the only attempts that have been made under very carefully selected weather-conditions have been about four night-flights between London and Paris. All of them were made in moonlight and with seven lighthouses along the course. Night-flying on a large scale seems unlikely to be realized in Europe as soon as the Air-Mail Service will realize it in this country.

MR. TARBOX:—What proportion does the expense of obtaining business, which was mentioned as being so great, bear to the total expense?

H. A. BRUNO:—We include in that the hiring of personnel. It includes passenger men and the operating of offices, which all comes under the head of our general advertising expense. It is difficult to set a definite figure but, in different localities, it is likely to run anywhere from 30 to 60 per cent, which is pretty high.

In regard to the life of commercial flying-boats, we have one ship, the Santa Maria, which has been in service for 3 years; it has flown 54,000 miles. It is in first-class condition. We have changed the engines, of course.

We have only one reserve flying-boat in the Cleveland-Detroit service, in which we maintain double daily operation from both cities, leaving at 9 a. m. and at 4 p. m. We have had only two instances of leaving late. We have maintained a perfect record across Lake Erie of 222 crossings; we have had no forced landings and no mishaps. We credit our mechanics and pilots with that record.

EDWARD SCHILDHAUER:—How many forced landings has your company had in all its operations?

MR. BRUNO:—In our operations between Key West and Havana during 1921, seven flights that were attempted were not finished. Three of these cases were due to fog; the others were due to engine trouble. In one case the boat came down, was fixed and then went on. In two other cases we sent out another boat and carried the passengers on their journey. That was during the entire Southern season, which runs from Nov. 15 to March 15. In the New York City operations, we have had three forced landings and two delays from fog which is prevalent in the early spring. There were no forced landings on the Great Lakes Division in 1922. On the Miami-Nassau run there were no forced landings. It was made then three times a week, but this year we are maintaining a regular daily service between Miami and Nassau. So far, since Dec. 1, 1922, there has been a 100-per cent performance on all Southern routes.

R. R. BLYTHE:—I have been criticized for referring lightly to safety but, as a matter of fact, I believe safety is and must be first in everything. My thought was that we could not wait for round-table discussions on airplanes that will be built in the future; we must use, improve as much as we can and sell what we have. The Aeromarine Airways, Inc., has had no fatal casualty as yet; how long that record will continue is conjectural. The company conducts the safer form of airplane transportation, its boats operating over water. If we should say that our present machines are not safe, and that we must scrap them and build some that will be safe, we probably would eliminate all of the present activity. We must improve the present equipment, but we must use it and sell transportation in it meanwhile.

ARCHIBALD BLACK:—It has appeared to me, for the past several years, that our big problem has been that of convincing the banker that we can make aviation pay. The demonstrations of the Aeromarine Airways, Inc., during the past 2 years has accomplished more in this direction than all of our discussions. I think that the whole industry owes a debt of gratitude to the officials and the operating personnel of this firm for their most constructive work.

INTERNATIONAL AIR CONGRESS

THE 1923 International Air Congress, which will be held at London on the invitation of the British Government, will open on Monday, June 25, and close on the following Saturday. The principal object of the Congress is to give an opportunity for an international discussion of the various problems in connection with the design, construction and operation of aircraft. The papers to be read will be divided into four groups covering the following subjects:

(1) Aerodynamics
Airplane Construction
Research Methods

(2) Powerplants
Fuels
Lubrication
Propellers

(3) Air Transport and Navigation

(4) Personnel
Air Tactics and Strategy as Affecting Commercial Design
Airship Design and Construction

In addition to the sessions of the four groups, which will be held simultaneously, an opportunity will be afforded to visit various British aircraft establishments and factories. Also, the Air Ministry has arranged to hold the Royal Air Forces Pageant on June 30, the last day of the Congress.

Membership is open to nationals of all countries that are represented on the Federation Aeronautique Internationale or are signatories of the International Air Convention. Further particulars regarding the Congress can be secured from the general secretary, Lieut-Col. W. Lockwood Marsh, 7 Albemarle Street, London, W. 1.

Discussion of Papers at the Annual Meeting

THE discussion of the papers presented at the recent Annual Meeting of the Society included written contributions submitted by members who were unable to be present and the remarks made at the meeting. In every case an effort has been made to have the authors of the several papers reply to the discussion, both oral and written, and these comments, where received, are included in the discussions. For the convenience of the members, a brief abstract of each paper precedes the discussion, with a reference to the issue of THE JOURNAL in which the paper appeared, so that members who desire to refer to the complete text as originally printed and the illustrations that appeared in connection therewith can do so with a minimum amount of effort.

In addition to discussion given below the discussion of Safety and Comfort as Inducements to Air Travel, by R. R. Blythe; Passenger Carrying Flying-Boat Operation, by H. A. Bruno; and A Critical Study of Modern Automotive Vehicle Steering Systems, by Herbert Chase is printed elsewhere in this issue of THE JOURNAL. The discussion of V. H. Gottschalk's paper entitled Society's Research Sheds New Light on Fuel Problem was printed in the February number of THE JOURNAL in connection with some supplementary data that were received too late for inclusion in the paper when it was printed in the January issue of THE JOURNAL. The discussions of the other papers, Testing of Leather Substitutes and Top Materials, by J. B. Davis; Aircraft-Engine Practice as Applied to Air-Cooled Passenger-Car Engines, by S. D. Heron; Experimental Survey of Gasoline and Kerosene Carburetion, by C. S. Kegerreis and G. A. Young; Cooling Capacity of Automobile Radiators, by E. H. Lockwood; Cheaper Closed-Body Construction, by George J. Mercer; Laws Governing Gaseous Detonation, by Thomas Midgley, Jr., and Robert Janeway; Needless Hardwood Lumber Waste, by Frederick F. Murray; and Automobile Finishing Varnish, by L. Valentine Pulsifer, will, it is expected, be published in the May issue of THE JOURNAL.

INTERNAL-COMBUSTION ENGINE CHARACTERISTICS UNDER HIGH COMPRESSION

BY J. H. HOLLOWAY, H. A. HUEBOTTER AND G. A. YOUNG

THIS paper is a report of a series of tests conducted during the summer of 1922 by the authors at the Engineering Experiment Station of Purdue University. The work consisted of research into the operation of internal-combustion engines under comparatively high compression on ordinary gasoline without detonation. The compression-ratio of the engine was 6.75 and the compression pressure was 122 lb. per sq. in., gage. The ingoing charge was passed through a hot-spot vaporizer and thence through a cooler between the carbureter and the valves. Jacket-water temperatures between 150 and 170 deg. fahr. were carried at the outlet port of the jacket.

The theory held by the authors as to the causes of detonation of the combustible charge is presented briefly. The source of the two phases of detonation encountered in this work is believed to be overheated areas in the combustion-chamber. The methods of combating these hot spots are given in detail, and the special equipment applied to the engine to accomplish the desired result is described. The effects of load, speed, compression-ratio and mixture-ratio are studied, and curves showing the variation in the engine characteristics due to each factor are submitted. All tests were run without a trace of detonation.

The results of the work point to the following conclusions:

(1) Automobile engines designed to give a uniform cooling of the combustion-chamber walls will permit the use of much higher compression-ratios than those employed at present, with a consequent gain in engine power and economy

(2) The fuel-air ratio for maximum economy borders upon the lean limit for reliable combustion

(3) For maximum power, the mixture-ratio need not exceed 0.075 lb. of gasoline per lb. of dry air

(4) With concentrated heating of the mixture at the carbureter outlet, a local temperature of 125 deg. fahr. is sufficient to give good operation at full throttle. Cooling to 100 deg. fahr. at the valves is desirable if the compression pressure of the engine is high. At part loads, a hot-spot temperature of 175 deg. fahr., with or without intermediate cooling, will give good results with lean mixtures

[Printed in the January, 1923, issue of THE JOURNAL.]

THE DISCUSSION

THOMAS MIDGLEY, JR.:—A peculiar thing about the paper is that the type of fuel used in these tests is not described. I presume the authors are aware that compression pressures of 200 to 250 lb. per sq. in are possible, if the proper fuel is selected. I presume that commercial gasoline was used in these tests, but I want to emphasize that when engine tests are reported with respect to detonation we ought to make a complete story by including the characteristics of the fuel used; otherwise a paper will be absolutely useless in the future, for nobody will know what it is all about. If the fuel data are added, the paper becomes a permanent record of a real accomplishment.

To operate an engine on commercial gasoline at 122 lb. per sq. in. compression-pressure is certainly a real

achievement. The authors state that they believe this would not be feasible in actual practice, but every automotive engineer will serve himself and his product if he will do precisely the things that have been done at Purdue University in reducing the tendency to overheat the charge in the cylinder.

EDWARD D. THURSTON:—Will Mr. Holloway give the temperature and the proportions of the various fuels? It would be interesting to know how the point of best power and the point of best economy compare with the mixture that is chemically best.

SYDNEY G. TILDEN:—Will Mr. Holloway tell us his experience with regard to sensitiveness toward carbonization in operating at these high compression ratios? Is it necessary to clean out the carbon very often?

J. G. VINCENT:—In this paper a mass of experimental data that confirms the findings of many investigators along these lines is presented in a condensed form. In this instance, however, a serious attempt has been made not only to run-down the obstacles in the path of further progress but also to devise a means of overcoming them. I believe such practical efforts on the part of our University research men deserve the highest commendation.

It is to be noted that the results have been obtained with a four-cylinder knight-type engine and, although I believe the conclusions reached can be applied to other engines, I still think that in future work of this character similar data should be collected on up-to-date poppet-valve engines that are in the vast majority at present. In laboratory work of this character one is apt to lose sight of certain fundamental requirements of road operation. In mentioning certain of these factors I should like to go on record as stating that this discussion is offered in a constructive spirit and in the hope that some of these problems will be studied in the laboratory at greater length.

The prospect of using higher compression in automobile engines is a particularly alluring one in view of the handsome gain in power and the reduction in the fuel consumption to be attained in this manner. However, I have found that even when detonation is entirely suppressed and a high-compression engine, showing say 100 to 110 lb. per sq. in. gage compression, is driven on the road at ordinary speeds there is a distinct loss in smoothness of operation which cannot be overlooked. It is, of course, a well known fact that it is the compression-ratio, and not any particular compression-pressure, that largely determines the shape of the expansion curve. I judge, therefore, that the more rapid rise of the pressure in the high-compression engine is responsible for the loss of that smooth flow of power that we associate with up-to-date engines having more conservative compression-ratios.

Another disturbing element militating against the use of higher compression-ratios is the formation of carbon in the combustion-chamber. There is yet to be devised a lubricating system that will lubricate the cylinder walls adequately and yet not permit any oil to rise in the combustion-chamber. In other words, apparently, carbon troubles will always be with us and, no matter how well we cool the piston-heads, the spark-plugs and the exhaust-valves, carbon will gradually accumulate and detonation will follow. It has been my experience that if two cars are started out on the road, identical in every respect except that one has, say, 70 lb. per sq. in. compression, measured at about 120 r.p.m., and the other about 85 lb., and subject these two cars to the same driving conditions, the one with the higher compression will have to have the carbon removed about twice as often as the one with the lower compression. Viewed from this standpoint, it appears that the use of higher compression-ratios must await the commercial development of non-detonating fuels.

CHAIRMAN H. L. HORNING:—I suggest that Mr. Holloway take into consideration the part of Mr. Vincent's remarks that calls attention to the rough running when the engine was still short of detonation. That is a very important point and represents the zone of the factor of safety, we might say, that must be allowed below the compression-ratio that will run without the audible detonation that occurs and that is so disagreeable.

STANWOOD W. SPARROW:—Since many of us are working along very much the same lines, if Mr. Holloway would describe a few details such as the method by which he cooled the spark-plugs, it might be of convenience and save considerable time for other people who are trying to do the same sort of thing.

I think there has come to be a more general recognition of the importance of compression-pressure rather than compression-ratio. This was emphasized by Mr. Midgley at the 1922 Semi-Annual Meeting as well as just now by Mr. Holloway.

In regard to definition of terms used, the thing that has given the most trouble, in which the most improvement has been made by Mr. Holloway, is what seems to me to be more like preignition than what I term detonation. However, although it would be desirable if we could agree as to what should be termed *detonation* and what preignition, it is much more important that both be recognized as obstacles to the use of high compression.

S. D. HERON:—Complete elimination of detonation does not appear to be necessary with aircraft engines. The maximum output and a minimum fuel-consumption are usually obtainable only with intermittent detonation.

It is pointed out in the paper that much can be done to eliminate detonation by reducing the internal temperature of the cylinder-walls. Some recent investigations with aircraft-engine cylinders indicate that conditions exist where the above statement does not hold and that high cylinder-wall temperatures do not necessarily have such a deleterious effect on the performance as has been commonly supposed. The engineering division of the Air Service has been working with cast-iron air-cooled cylinders and has found it possible to obtain a high output with cylinder-wall temperatures hitherto considered impossible. With a 4½-in. bore and a 5½-in. stroke cylinder, using a mixture of 80 per cent aviation gasoline and 20 per cent of benzol as fuel, as much as 155 lb. per sq. in. indicated mean effective pressure has been obtained, with combustion-chamber-wall temperatures of over 700 deg. fahr. The combustion-chamber form appears to have a decided influence upon the wall temperatures that can be used without causing excessive detonation. The performance quoted above was obtained from a cylinder with overhead valves and an almost completely hemispherical combustion-chamber. Past experience with overhead-valve flat-head air-cooled cylinders has shown that combustion-chamber-wall temperatures of 700 deg. fahr. are productive of such violent detonation as to prevent continuous full-throttle operation.

PERCIVAL S. TICE:—The point raised about the shape of combustion-chambers has been very well taken. Will Mr. Holloway tell us what he can about the apparently direct effects of the mixture-temperature in this latter compression arrangement?

CHAIRMAN HORNING:—How does Mr. Holloway ac-

count for the low thermal-efficiency with a 6.5 compression-ratio? I calculated that he should get 34.4 per cent indicated thermal efficiency, but he obtained only 30.4 per cent. In other words, he lacks about 4 per cent of obtaining good performance.

J. H. HOLLOWAY:—The fuel used in all of these tests was Red Crown gasoline, such as we get in Indiana. The mixture-temperatures for good performance are given in conclusions 10 and 11. The mixture-ratios for best power at full throttle and for best economy at partial throttles are specified in conclusion 5. The chemically perfect mixture contains approximately 0.067 lb. of gasoline per pound of dry air.

We had a little carbon deposit in the combustion-chamber, the piston-head and the cylinder-head being the only available places for deposit. By running at from one-half to full-load most of the time, the carbon that formed seemed to curl up and chip off. We had very little carbon deposit with the proper mixture-ratio, but we did find that little particles of carbon that gave some trouble formed on the ports of the sleeves. That probably was, within a reasonable time, as we know it, for cleaning the carbon; not 2 or 3 days or a week. After a couple of months of running we would show up some color in that way, but we made it a practice never to clean the carbon off the cylinder-head or the piston-head.

We agree with Mr. Vincent that the poppet-valve engine offers a promising field for research along the lines of high compression. The ability to carry high compression-pressures seems to be purely a matter of keeping the exhaust-valves below the temperatures that will induce detonation. Careful water-jacketing of the valve-seats, small valves and multiple spark-plugs should make high pressures practicable in poppet-valve engines.

We might suggest that high compression-pressures with their attendant high explosion-pressures require an increase in the flywheel size to give a smoothness of operation comparable with that of a low-compression engine.

It is questionable whether high compression results in an increase in the rapidity of carbon formation. It is obvious, however, that the higher temperatures before ignition due to high compression will make an engine sensitive to carbon deposits.

The details of the spark-plug and the special head are illustrated in Fig. 2. The mica core and its gland are held by the steel shell that is shown in the upper left-hand corner. The lower end of this shell is screwed into the cylinder-head shown at the right of the illustration and replaces the standard spud that is cast integrally with the conventional cylinder-head and holds the top of the water-jacket in place. The water is in contact with the steel shell, which eliminates a threaded joint and a thickness of metal between the core and the jacket water, thereby facilitating the transfer of heat from the core. The question about the definition of detonation is rather a delicate one. Every one seems to have his own idea about it, and many of the ideas do not agree very well. It seems that we have two kinds of knock; that is, a knock that is like a "ping," and a knock, a dull heavy thud, that succeeds this ping when the spark is retarded. I do not know whether they are both caused by detonation. I am satisfied that the latter one is. It may be that the other is also, but it occurs at a different point on the stroke of the engine. For instance, if a detonation occurs from the hot-spot end of the cylinder, the explosion would occur well ahead of the dead-center in that case, or at some place ahead of the dead-center. If there is an early spark, the same sound is present. If the spark is retarded after a period of detonation, the sound seems to turn into this dull, heavy thud; so it is pretty hard to state, in my mind, just what detonation would be there. We have to distinguish between the two in some way.

Regarding Mr. Heron's question on wall temperatures, we always attempt to keep the wall temperature as low as possible; that is, consistent with the possibilities in practical operation. We run our outlet-water temperatures from around 170 to 190 deg. fahr., and the higher the wall temperature is, the sooner the engine apparently shows some detonation. We found also that whenever detonation starts from one cause or another, such as choked circulation or insufficient cooling, the power falls off very rapidly.

As to the effect of mixture temperature, raised by Mr. Tice, I think it is one of the most important features along this line. It seems to me that the detonation that occurs is dependent upon the initial temperature of the charge, of course, after the charge has gone through the process of combustion the temperature is raised; so that, the lower the start is of mixture temperature, consistent with good distribution, the less tendency there is to detonation. This is an important point in this problem.

I agree with Mr. Horning that the thermal efficiency at full throttle is low, due to the fact that the spark was given an advance of only 5 deg. The investigation was carried out to apply to automobile service and, since the major portion of the running was assumed to be done at partial throttle, the efficiency at full load was sacrificed in favor of the efficiency at part load. At three-fourths of full power the indicated relative efficiency based on the air-cycle is 60 per cent. I do not know on what basis Mr. Horning computed the efficiencies that should be obtained at the compression-ratio adopted.

O. C. BERRY:—How was the heat value of the fuel determined? I feel that I may be in error in my own work in using the higher heat-value of the gasoline. When we attempt to compare our thermal efficiencies with those reported by the English, we find that we make rather a poor showing, as their figures are based on the lower value.

I think it is important also to have an exact statement of how the friction horsepower has been obtained. I have been using three ways. One of them is by cutting out one cylinder at a time and subtracting the total horsepower on that basis from the horsepower of all the cylinders. This gives a very pleasing result because it makes it appear that there is almost no engine friction. Then, when the measurement is made by motoring the engine with the dynamometer, we are surprised to find at least twice the friction horsepower that we found previously. The most accurate method of measuring the friction probably is to use the balanced diaphragm meter, as designed at the Bureau of Standards. At any rate, in making a report of this kind, we ought to be very careful to bring out all this information, so that we may be able to interpret the results accurately.

MR. HOLLOWAY:—The heat value of the fuel we used was based on the lower rating; that is, 18,900 B.t.u. This value was given by the Standard Oil Co. The friction horsepower was obtained from the dynamometer by motoring the engine.

MR. MIDGLEY:—Red Crown gasoline is one thing in one place and another thing in another place. The brand "Red Crown" is not a specification for gasoline. In Indiana, we find that we will have a large sulphuric acid absorption where the Red Crown gasoline is pretty highly unsaturated. I would like to have a description of the

fuel, comprising the distillation curve, unsaturation, specific gravity and temperature of critical dissolution with aniline after being washed with sulphuric acid. Those four figures give a pretty fair criterion of what the compression value of the fuel is.

MR. TICE:—There seems to be confusion about the mixture-ratio statement. We all have the habit of speaking in terms of pounds of air per pound of fuel. All the literature includes that method of statement. Cannot the Society standardize on one thing or the other?

CHAIRMAN HORNING:—I, also, have had great difficulty in following the method of expressing the ratio of fuel weight to air weight. I think the English started, with the work of the Gaseous Explosions Committee, to express the ratio thus, 13-1, or the weight of the air to that of the fuel. So, when it comes to expressing it decimally, it is not clear to me.

What heat value, in British thermal units, is used when figuring the thermal efficiency? That is an important point because some of us are claiming some very high thermal-efficiencies. Our company figures on the basis of 19,400 B.t.u. We get somewhat over 20,000 B.t.u. in much of our fuel.

E. H. SHERBONDY:—In this connection, for the first tests in blast-furnace-gas work there is one value in natural gas and in the various artificial gases there are different heat-values, the rating always being on the basis of British thermal units per brake horsepower. I think that would be a very much more satisfactory basis for rating, than to rate on the basis of pounds.

CHAIRMAN HORNING:—Mr. Midgley, what heat value do you use for that Red Crown gasoline?

MR. MIDGLEY:—In round figures, 20,000 B.t.u. per lb. I feel that the actual value is the only value to use and that it really should be the lower heating-value. The arbitrary way of stating it at 20,000 B.t.u. or 19,400 B.t.u. or whatever value one may select, undoubtedly has been fairly satisfactory during the last 10 years, but we are looking forward to a period when benzol, alcohol and materials with different ratings per pound will come into use. We will not be able to standardize on those things nearly so readily in the future. For the future, we ought to look forward to the actual rather than an assumed value. We have used 20,000 B.t.u. just because it is a round number, and for no other reason.

CHESTER S. RICKER:—Is it not a question whether you are using the higher or the lower calorific value of the fuel? Is it not a question of whether you are considering that the by-products include water that goes away as steam?

PROF. W. E. LAY:—We have been using from 19,600 to 19,800 B.t.u. at the University of Michigan.

W. S. JAMES:—At the Bureau of Standards the lower heating-value has been used and usually it has been determined experimentally. The lower heating-values have been used because it is believed that the higher heating-value, including the latent heat of the steam that is formed during combustion, is an ideal figure that has no real significance in an engine of the type now used.

JOHN W. STACK:—We usually state the heat value at 19,400 B. t.u., as being the low value. The high value is sometimes 21,000 B.t.u.

H. S. MCDEWELL:—If a heat value for the fuel has not been assumed, that information is conveyed just as well by the fuel consumption. One is only misleading himself if he states a thermal efficiency on that basis. With the ordinary commercial gasoline about 20,500 B.t.u. is the high value. I believe in using the high rather than the low heat-value, because that is what is put into the engine.

MR. RICKER:—Valve-timing is not mentioned in the paper. You speak of compression-ratio, yet what does it really mean? You can move the compression up and down the horsepower curve so readily by changing valve-timing that, without a knowledge of the actual valve-timing of an engine, little is known about the compression and the effective pressures in the combustion-chamber.

MR. HOLLOWAY:—The valve-timing used was the standard timing of the Willys-Knight engine.

CHAIRMAN HORNING:—We have demonstrated that there are a number of different heat-values in British thermal units used for fuel; it is a subject that the Society and the Research Committee could well take up. It is very important to know exactly the value of the fuel and the correct lower-value when making scientific investigations of an engine. It is very serious, for instance, if an Englishman or a Frenchman says that he gets a 33-per cent indicated thermal efficiency, for him to be figuring on one basis and for us to be figuring on another. We simply cannot compare the readings. I have found it very difficult, in getting the relative efficiency, where comparing with the other fellow.

A. A. BULL:—Referring to the report of the tests conducted with high compression, the first impression is the apparent ease with which satisfactory operation without detonation was obtained. There are some interesting disclosures, however. In propounding the theory of detonation, it is stated that "unless the heat, due to this latter compression, is transferred to the combustion-chamber walls as rapidly as it is generated, the temperature of the entire mass of the gas rises to the ignition point and explodes instantaneously." Surely, this needs some qualification, as the heat-loss, if this were true, would greatly reduce the effective work done in expansion. This condition, however, introduces the question as to what influence the stroke-bore ratio has on the expansion characteristics and its effect on detonation.

In summarizing the salient features that permit carrying high compression, reference is made to the necessity for comparatively cool exhaust-valves. It is unfortunate that actual temperatures in the engine under investigation were not obtained, so that the limit to which these temperatures can run could be determined. In this connection the factors that affect the exhaust-valve temperature, the valve-timing, the seat width and the proper cooling of the seat, should certainly receive strict attention if the valves exercise such a distinct influence on high compression.

The necessity for aluminum pistons in place of those made of gray iron is, of course, in accord with prevailing general opinion, except that the benefits are minimized considerably by the presence of carbon in actual service.

It has been our experience that higher mixture-temperatures do influence detonation; but, on the other hand, instances have occurred where abnormal heating actually has reduced the tendency to knock. It appears to be essential that heat control be provided in proportion to the throttle opening, limiting the temperature under open-throttle conditions.

It is interesting to observe the results obtained by the use of the sleeve-valve engine, which seem to indicate that the higher valve-temperatures do have a decided bearing. Perhaps the most significant portion of the results is the reference to the spark-advance at full load, but it is not clear whether the spark-advance of 5 deg. at full load was the maximum that could be used to avoid detona-

tion, or the spark-advance that was necessary to obtain the maximum power. Unquestionably, the spark-advance has a very decided influence, the importance of which is perhaps not generally recognized, particularly on heavy-duty engines. In this connection the combustion-chamber design had a distinct bearing; for instance, it happens frequently that the spark-advance required for the maximum power is in the zone of detonation, and a reduction in the spark-advance away from the zone of detonation reduces the power. I have in mind some experiments conducted along this line, clearly showing the possibility of having a considerable range between the spark-advance that would produce detonation and the reduction in the spark-advance that was possible without reducing the power. This range was between 24 and 14 deg. at 1000 r.p.m. The control of the spark-advance, in proportion to the throttle opening, is worthy of more consideration. It is true that the higher compressions that provide better combustion conditions make it unnecessary to have the ignition point so far ahead of the upper center as is usually necessary, and the combination of the two factors increases but very little the tendency to knock. The influence of high compression under actual operating conditions must be taken into consideration. The presence of carbon, which is more or less inevitable, and many other factors, prohibit the use of compressions that, from a theoretical standpoint, are ideal. Some control can be exercised over this, however, by arranging a compression curve properly, so that the lower compressions exist at the lower speeds, under which conditions the knock is most pronounced.

MR. HOLLOWAY:—The factor that apparently has a decided influence on detonation is the manner in which combustion proceeds after inflammation has been started by the electric spark. If the reaction is carried to completion by the normal propagation of the flame-front, no detonation will occur. If the entire charge in the combustion-chamber reaches the ignition temperature simultaneously, however, the explosion-pressure will be terrific. The logical method of maintaining normal combustion conditions is to prevent a rise in the temperature to the point at which the action is instantaneous. The effect of the combustion of the initial portion of the charge is to compress all of the unburned gas and in that way to raise its temperature. One way to limit this temperature-rise is to provide an avenue for the dissipation of the heat in the gas and thus to give no chance for detonation. A path for the escape of sufficient heat to prevent detonation would not necessarily involve an appreciable increase in the radiation loss during the expansion stroke. With the high temperatures of the burned gas, the change in the cylinder-wall temperatures required to affect the rate of heat-transfer noticeably would be much greater than that necessary to overcome detonation.

TESTING FUELS FOR HIGH-COMPRESSION ENGINES

BY STEPHEN M. LEE AND STANWOOD W. SPARROW

THIS paper is concerned with certain of the methods used and results obtained in two investigations of fuels for high-compression aviation engines. The fuels in question are benzol and ethyl alcohol, either alone or as blended with gasoline.

The necessity of mixture-ratio runs in fuel investigations is vigorously emphasized. In that the tendencies of a fuel to detonate or preignite limit the conditions under which it may be used, methods of estimating these characteristics are discussed. Also a graphical representation has been made to illustrate the relation between compression pressure, compression-ratio, volumetric efficiency and indicated power in order that, with a given engine, the effect on detonation of changing engine conditions may be estimated.

Results characterizing the performance of the different fuels are mentioned and particular attention is directed to cases where these results are in contrast with current opinion. [Printed in the January, 1923, issue of THE JOURNAL.]

THE DISCUSSION

E. H. SHERBONDY:—What is the heat-value of benzol?

STEPHEN M. LEE:—The heat-value of motor benzol was taken at 17,300 B.t.u. per lb., the lower heat-value.

CHESTER S. RICKER:—Some controversy has arisen in regard to the bad effect on the life of the valves, of burning benzol in an ordinary engine. What experience have you had in this regard?

MR. LEE:—When using the blended fuels and high ratios the valves were not found to be any more burnt or worn than with gasoline at the lower ratios.

MR. LIPTON:—Fig. 7 of the paper shows volumetric efficiency. What temperatures were indicated in the intake-manifold?

MR. LEE:—The air temperature at the entrance to the carbureter of the one-cylinder engine was maintained constant at 30 deg. cent. (86 deg. fahr.). The intake-manifold temperature was not taken.

CHAIRMAN H. L. HORNING:—It is evident that we can run at much higher compression than we are using at present.

MR. SHERBONDY:—In connection with these tests, a point not very generally appreciated relates to the fuel consumption and the thermal efficiency where a constant pressure enters. We have all heard about the wonderful efficiency of Diesel engines, and these tests bear out the theory that the fuel consumption of the constant-volume engine can be much lower than that of the constant-pressure engine. The idea seems to be very prevalent among engineers the world over that the constant-pressure cycle is more efficient than the constant-volume. This is not borne out by actual tests. Recently, I witnessed a test of a good-sized Diesel engine. It was rated at 135 hp. and weighed about 250 lb. per b. hp. The builders thought they had a very light, very efficient engine. The fuel consumption was about 0.58 lb.

MR. LEE:—The efficiency of an engine operating on either the constant-pressure (Diesel) cycle or the constant-volume (Otto) cycle depends upon the expansion-ratio. Usually the expansion-ratio of a constant-pressure engine is higher than that of a constant-volume engine. The purpose of this work is to make possible an increase in the expansion-ratio of engines operating on the constant-volume cycle. I would like to ask Mr. Sherbondy whether the fuel-consumption figure he quoted for the Diesel engine was per brake-horsepower hour or per indicated-horsepower hour?

MR. SHERBONDY:—Per indicated-horsepower hour.

THOMAS MIDGLEY, JR.:—A member of a firm of Diesel

engine builders in Germany, who is a high-grade engineer, showed me the results of an experiment conducted on an automotive-size Diesel engine, giving 0.68 lb. per hp-hr. at one-quarter torque; I showed him the tests of a 7-to-1 compression-ratio, Chevrolet engine that gave 0.67 lb. per hp-hr., and he acknowledged that such results, with the knock eliminated, meant that there is only a very limited field for the Diesel engine in automotive work.

W. S. JAMES:—Regarding the relative efficiency of the constant-pressure and the constant-volume cycles, the efficiency of the constant-volume cycle is dependent upon the volumetric expansion-ratio. In the constant-pressure cycle the efficiency is dependent upon the expansion-ratio at the time when expansion begins. The Diesel engine may therefore be inherently handicapped by the fact that a significant interval of time is required to ignite and burn the fuel before the actual expansion starts.

CHAIRMAN HORNING:—That is an excellent distinction. I will read some fuel-consumption figures in pounds per indicated-horsepower-hour taken from an engine that has been on the road for 3 months and was found satisfactory by the driver for accelerating power and the like. At 600 r.p.m., 0.487 lb. per i. hp-hr.; at 800 r.p.m., 0.474 lb.; at 1000 r.p.m., 0.463 lb.; at 1200 r.p.m., 0.450 lb.; at 1400 r.p.m., 0.440 lb.; and at 1600 r.p.m., 0.430 lb. When we showed that to a Diesel-engine man, he collapsed.

S. W. SPARROW:—In regard to roughness of operation with the high-compression engine, the engine ran as smoothly and with no more vibration at the 14 to 1 compression-ratio as it did at the low compression-ratio. If high-compression engines have shown this roughness, it probably has been a case of preignition that was not pronounced enough to diminish the power seriously, and yet was not audible as detonation. That is very much the thing that Mr. Holloway has been working to eliminate. Such preignition may make an engine operate very roughly although with only a small decrease in power and with no audible detonation.

MR. MIDGLEY:—This matter of roughness is a bugaboo. We made a mistake when putting up a high-compression engine. We planned to make the ratio 7 to 1, but we found we had to leave an extra 1/16 in. on top of the piston and this gave a 225-lb. per sq. in. compression. That machine is being driven every day and has been driven for 10 months and is entirely satisfactory. There is no roughness; it is just as smooth as an engine is normally. I drove a Chevrolet car having a 160-lb. per sq. in. compression-pressure one summer; there is no roughness.

MR. SHERBONDY:—One practical point in connection with detonation is cylinder construction. Loose-head engines are fairly common now, but the great disadvantage of a loose-head engine is the very high charge-temperature that attends its use. I believe it is impossible to get anything like the mean effective pressure with the loose-head engine that can be obtained with the other type. Another problem is that of thin versus thick cylinders.

MR. RICKER:—On an engine with which I was experimenting we increased the compression about 25 or 30 lb. per sq. in. and experienced the roughness that J. G. Vincent mentions. A little later, we ran the same engine with different manifolds that were designed to give more uniform distribution and the roughness was gone.

CHAIRMAN HORNING:—One of the ways of telling where you are wrong is to listen for detonation in the various cylinders and find out whether the manifolds are wrong as to distribution and so find out which cylinder is getting the most charge. In a very recent test, the best fuel-consumption was 0.510 per b. hp-hr., but, by modifying the manifold, it went down to 0.485 lb. That was all that was done. It really should have been 0.440 lb. The difference between 0.440 and 0.485 lb. per b. hp-hr. was chargeable almost entirely to distribution.

IMMEDIATE POSSIBILITIES OF COMMERCIAL AIRPLANE SERVICE

BY C. G. PETERSON

STATING that the heretofore impassable barriers to commercial aviation have been costs and the lack of desire of the public to fly often, or to fly at all, the author proposes that the public, which must constitute the market for airplanes on a commercial basis, be educated by a demonstration of safe and reliable payload airplane-service extended over an indefinite period, and outlines a plan that includes the surmounting of cost deterrents.

He marshals arguments and statistics to show that such a public demonstration can be made by a proper and adequate equipment, operation and maintenance of the Aerial Mail Service, since it has been demonstrated already by this service that mail can be carried safely by air and that it can be flown through hard Northern winter weather. His statistics include a consideration of the present volume of mail, special-delivery-letter and parcel or package-carrying possibilities as revenue producers, being inclusive also of the postal rates necessary under such conditions.

An estimate on the cost of equipping and operating a night-flying line between New York City and Chicago, based on present equipment, is given. The author believes that passenger traffic would follow unsolicited just as soon as the public realized that the mail airplanes were flying safely and on time. [Printed in the March, 1923, issue of THE JOURNAL.]

THE DISCUSSION

C. G. PETERSON:—We will need the support of every one in the aeronautical industry when the time really comes to influence Congress. The bill that will be required can be written in 10 lines. All that is needed is for Congress to authorize the Postmaster General to let contracts for carrying mail. If such a bill is passed, the appropriation will follow. It need not be large. As soon as real commercial aviation comes through at carrying the mail, we can expect the public to start flying consistently right after that.

CHARLES M. MANLY:—The important thing that we must do for aviation is to find work for it. The remarks of the speakers have all tended toward this one big and important point of keeping the industry going and finding means of keeping it going. The thing that keeps all industries going is selling the goods. The situation in connection with aviation is that we must find susceptible customers and build up a business by selling what we have. Mr. Peterson has pointed to mail service as being a very important line to sell, and I think this is one of the things that we should work on to create a strong favorable sentiment. If we could show the farmer how this would benefit him, we would get appropriations at

once. If we can show him that air-mail service brings him nearer to the city, we can get an appropriation, even if it involves a loss to the Post Office Department. To get the farmer's mail to him quicker, or take something that he wants to him, will help to sell commercial aviation. We must cudgel our brains to sell this proposition. I feel less downcast over the situation than many probably do, because I have passed through still worse stages of it.

Aviation will go on, but if we are to build up an industry we must sell what we have and not sit around and simply wish and hope. The big thing is to keep hammering on the proposition of selling mail service here, overwater transportation from Florida, Detroit, Cleveland and other places, thus getting the cumulative effect of it all and in that way building up the business.

Mr. Peterson also mentioned that no airplanes have been produced and sold for commercial purposes at a profit that were complete new machines. That is a serious situation; however, it is partly tied up with the fact that production is not yet great enough to justify quantity-production methods. Also, many of the things that we have to use are very expensive anyhow, and possibly economics enters in that we have a quantity of equipment that was built during the war and it is natural to keep on trying to use it to reduce the expense.

There are many places where aviation can be used, however, if more of us will give our time to trying to sell the thing and fewer of us try to invent new machines and improve some theoretical design. The big thing today is to sell aviation and to sell the Government on the idea that it must build up its military power through having the factory facilities and having these designs worked out completely. There is no excuse today for our military services being in such a situation that they cannot immediately pull the blueprints out of the files and order machines built according to them. We ought to have learned our lesson from the last war on that. The most expensive thing we had was delay. So, we must sell the military side as well as the Post Office Department. Then we must sell aviation in all these other applications, such as carrying passengers, light express matter and the like. We must utilize the places where we have the greatest chance to make the best showing on the economics of it.

C. D. HANSCOM:—I was rather surprised when Mr. Peterson brought out the fact that it only takes 1 cent per letter to carry the mail. I had suposed it was 1½ cents. If my figures are correct, his estimate of 200,000,000 letters per year would give something like 13,000 lb. per day and, with that amount of mail, I think that his figure can be beaten. I think that we can carry a letter for 0.8 cent from New York City to Chicago, terminal to terminal; that is, without profit. For 1 cent, which is the amount that is left after the Government gets through, we would have a reasonable profit included. I think that we actually can make a commercial proposition of the mail under those conditions now. Certainly we should be able to with the additional express and special service that would be available.

LEE D. WARRENDER:—Regarding the need of educating the public, last fall when the races were on a blimp burnt up down in Texas and there were big, flaring headlines across the tops of the newspapers. When I went into an engineer's club, a practical engineer said: "Is that one of the machines that made the speed record last week?" If that is the extent of ignorance among people who should know better, public education is a very serious problem and is a momentous one to tackle and handle.

Regarding noise, I was making a flight from Dayton to the City of Washington in one of the Martin bombing airplanes and I became tired and went to sleep riding in the front cockpit; I was asleep for at least 1 hr. right between the two engines. I did the same thing going from Indianapolis to Dayton, flying in a Liberty. If one person can be educated to be able to sleep in an airplane, the same thing can be done with the public.

Practically everybody here seems to be afraid of metal construction. They speak of it and pass it by. I think they are afraid because, in the past, most of the airplanes have been made out of wood. They know wood; it is easy to work and they do not go to people who have had experience in metal construction; they will put some man who has never had any experience with metal construction in charge of all that work.

With regard to the comparative operation of wood-working and metal-working machinery, the former is built to work with limits of ± 1/64 in., and metal-working machinery is built to operate with limits of ± 0.0001 in., which gives a comparison of the quality of the machinery and the type of work that it can do.

EDWARD SCHILDHAUER:—To follow out Mr. Manly's argument, we must get to the farmer, because he is in the majority. There is no greater farming section than the Middle West. The finest landing-fields are there because it is a prairie. What the farmer in the Middle West wants is goods and mail from the East; he is interested in what is coming from a long distance.

It is not necessary that aeronautics be subsidized by the Government, or to go to the Government and ask for favors. If the aeronautic industry will layout a plan of action such as I propose, I believe that it can be put across by the business men of the Country because they will demand expansion. It is a fact that goods delivered by overnight trains can be delivered during the following forenoon by airplanes and advance the time of delivery. It is also a fact that airplanes cannot compete with trains that deliver goods produced at the starting point of the airplane because the trains have the advantage of the night schedule. The goods must come from a ride overnight to that point, and the airplane must start out in the morning. Airplanes cannot compete with trains unless they fly by night, and we have not yet arrived at the period in the expansion of airplane usage that enables an airplane to fly at night. I do not pose as an authority; but I have read about night-flying by airplanes, and night-flying of airplanes in fogs and landing in fogs. It is the consensus of opinion today that an airplane cannot land in a fog on a commercial basis; neither can it fly by night on a commercial basis unless the airplane route is laid out so that there is a landing-field that it can glide to, and this landing-field is ready and free of fog when the airplane wants to use it.

I propose that, since the goods to be delivered by airplane should have night travel to save time, a backbone-service of airships be established between New York City and Chicago, the airship to leave New York City at night and arrive in Chicago at dawn. From the same field, airplanes would then distribute to St. Louis, Kansas City, Omaha, Sioux City, St. Paul, Superior, Green Bay, Milwaukee and to the cities within that entire area. In the afternoon, additional airplanes would start from those points that are say 400 miles distant, and come to Chicago bringing the banking papers, the mail and other express matter that goes East. At night, the airships would leave Chicago and land in New York City and distribute there the next morning. This would provide a

backbone-service with an auxiliary service stretching out for the business. When we establish a service that will make a Chicago or a St. Paul man realize that goods purchased in New York today can be received by him tomorrow before noon, he would not care whether he paid 15, 20 or 30 cents per lb. for such quick delivery. That is not true for all goods, but I say that it is true for special goods. Out of the 400-odd carloads of express matter that originates in this metropolitan district daily, we may expect that from 50 to 60 carloads will go to Chicago and the Chicago gateway. Even at 10,000 lb. per carload, and a carload is usually 20,000 lb., one can calculate how much special material there should be in that mass of stuff to provide a load for airships. With an airship, we could transport one or two carloads readily; and, I dare say, when that service has been established, the business would come to it. The experience of the express companies has been that whenever they have established a faster route, business has traveled that route. The American Railway Express Co. will verify the fact that business will follow the route of the greatest speed. By the plan that I propose, we will get speed and get the airplane transportation where it belongs, as a feeder for the airship.

CHAIRMAN E. P. WARNER: — Mr. Peterson specified, when giving his figures for the New York City to Chicago air-mail line, that four airplanes would run each way each night and that there would be a total of 60 planes in service, with a 1000-hr. life for each airplane. It seems to me that this is a very excessive reserve. If we have to have a reserve of 650 per cent, the airplane is not good enough for commercial service at present; 200 per cent should be an ample reserve. An airplane life of 1000 hr. is not satisfactory; we ought to get a 3000-hr. life at least, and I think we can get that now, as a matter of fact, under proper conditions. That is the very minimum that should be considered for commercial operation.

We cannot depend on commercial operation to keep the aircraft industry alive even under a subsidy until it is tremendously magnified beyond anything that at present exists either here or abroad. Mr. Peterson's figures called for only 20 new airplanes per year on this New York City-Chicago route, and I think his figures are very liberal in that respect. According to the best figures that I could secure, the French Government is purchasing about 1500 airplanes per year at present for military purposes. It is subsidizing commercial air-lines. The French air-lines are taking about 60 to 75 airplanes per year, about one-twentieth of the military demand. The French factories are going ahead. I visited several factories and each of them is employing more than 1000 men on military-aircraft work at present. The question of the upkeep of the industry should be kept wholly separate from that of operation for the present. We cannot look to the commercial operating firm to keep the industry alive.

MR. PETERSON:—I cannot attempt to go into all the figures that I used in working out those estimates, in a short discussion such as this. I figured on 60 airplanes, keeping four in the air each way; a total of eight for the round trip. They would be operated on divisions the same as is done on the railroads. I would not attempt to fly one airplane straight through from New York City to Chicago. Figuring on three divisions, there would be 24 airplanes in the air per day; so the percentage in reserve is only a little over 200.

Mr. Schildhauer's idea is to establish first an airship route from New York City to Chicago. There is no doubt at all that, on long hauls, airships would eventually be cheaper and better than airplanes. The point is that in establishing an airplane route, we have the airplanes to begin with and can get the fields. For the establishment of such service, $2,000,000 is not an excessive sum; it is exceedingly small. But to establish an airship line, $2,000,000 is only a drop in the bucket. As to the airplane being used for radiating and furthering airship flights, that, of course, is one of the developments that is bound to come; but it seems to me it would be very disadvantageous to attempt to go as far at present as to ask support and subscriptions from the public for a vast airship line to operate between those two cities.

MILITARY-AIRPLANE DEVELOPMENT AND CONSTRUCTION IN PEACETIME

BY F. H. RUSSELL

THE reconstruction period since the war has served to establish aviation as an essential arm of both the military and the naval forces of the Government. This in itself is a real accomplishment. But for several reasons the airplane industry has not performed the service that was expected of it and has not received the support that is necessary for its existence. Although the expense is great, the development of aviation through the facilities at McCook Field and at the Naval Aircraft Factory has been hampered by red-tape and by the fact that the personnel of the Government agencies are at the same time the judges of new developments and the competitors of the engineers in the industry. The result is a feeling of reticence among civilian engineers with regard to disclosing and developing new ideas, the retarding of the advancement of service types, and slow deliveries. Although several companies at the close of the war were well equipped to produce airplanes cheaply and efficiently, these gradually have been driven out of existence and their places have been taken by smaller organizations that depend solely on casual orders which return small profits.

Competitive bidding has resulted in delay to the Government and loss to the manufacturer; in some instances bids have been asked on machines that had not been sufficiently developed to allow the Government to furnish blueprints, design data or a bill of material. The safety of the Nation is predicated on a dependable source of supply of equipment, especially aircraft. An important function of the Government, therefore, is to see that the engineering and production data are complete, uptodate and practical. This is not usually the case, the contractor being depended upon to complete and correct the data; and an unforeseen loss of time and money has been entailed. Early development of the art of aviation was due to the genius of a few men, but the development of the future will be by organization, with specialists in every line; the production of the world's fastest airplane at the races in Detroit is a case in point. Confusion has arisen through the custom of ordering new types in small quantities and of depending on competitive bidding for the further supply, on the assumption that when once completed the article was "commercial" and not proprietary.

The suggestion is made that the experimental work and the subsequent developments be confined to the same organization, with provision for production in large quantities in time of war. The Government's problem should be the selecting of airplanes for training and operating, and the guiding of the industry in developing such designs. Engineering and production should go hand-in-hand. Government subsidies, such as are customary in other countries, are not needed yet but production must be encouraged through the supply of Government equipment. Particular types of airplane should be considered proprietary, but the Government should be free to purchase any design at any time in any stage of advancement and place it by competition or assignment with recognized units in the industry.

Cross-licensing, originated as a war concession by patent owners, has had the effect of causing some persons to feel that any airplane should be purchased by open competitive bidding. But this agreement did not contemplate encouraging one manufacturer to use another's design or standardizing construction so that it could be used by all. Competitive bidding should be used only when a producer has been found incompetent or unwilling to furnish his product at a reasonable price under reasonable conditions. Considering each type of airplane as proprietary would make for permanence of business, encourage small companies to increase their facilities and guarantee to the Government a source of supply in time of peace and the distribution of data and personnel in time of national need. [Printed in the March, 1923, issue of THE JOURNAL.]

THE DISCUSSION

EDWARD WALLACE:—To correct an impression that has been given, I believe that the Government receives drawings from which it can build aircraft during wartime emergency. I believe that the Government has been supplied with drawings, specifications, bills of material and parts so complete and so accurate that if war should break out, it could produce aircraft in any quantity that it desired by subletting the various units of the machine to firms in various sections of the Country. I know of a company that designed and produced 20 machines in less than 12 months from the day they were started. The machines were accepted by the Air Service. Those drawings are now on file in the engineering division of the Army Air Service. The War Department also has special drawings for the Liberty-engined and other airplanes it is listing so as to be able to produce them. I say this in defence of the Air Service, which is doing very efficient work. Its bills of material are very efficient, although it may not be the privilege of every one to have come in contact with these bills of material.

When engineers concentrate to the extent that they should in refining fittings and using the materials of construction properly, such as distributing the material in its proper place, using it where it is most needed and making airplanes within the weights specified, we can gain the confidence of the public and of the Government and prove that we can actually build the planes as they are required. The thing that engineering societies and professional men should concentrate upon is actually to produce the goods. When that is accomplished, the people will believe that aeronautics is an accurate science. There is nothing very difficult about the structure of an airplane, although there are many things to learn. It requires only common-sense, persistence and concentration, so that nothing shall be overlooked.

Inspection is very important. An airplane must be complete as a whole, for one weak point may result in a crash. There is a possibility that, in the rush of things, these important factors in constructing airplanes will be overlooked and so cause adverse public opinion.

Recently, I saw a catapult about 50 ft. long that will throw a large airplane into the air so that it can fly off at a speed of about 60 m.p.h. If people can see airplanes shot into the air from the tops of post office buildings and flying off safely, then we shall see a change in public opinion.

In defence of the Post Office Department, I will say that its airplanes have flown more than 1,000,000 miles without any trouble. The department is actually building some of its own airplanes to carry 800 lb. of mail and is doing it very efficiently. Thus it has developed trained workmen who know how to build the airplanes and inpect them properly.

A. KLEMIN:—Is it not possible that we are all hanging too much onto the skirts of the Government? The Air-Mail Service and the Army have been suggested as aids, but we want the public to help us; we want the public to become interested and sold on aviation. Could we not do more by selling aviation on an industrial basis? I have in mind selling aviation in the way, for instance, that the Loening Aircraft Corporation is selling it. This company has a well-defined policy of selling a high-grade product at, perhaps, a seemingly very high price; but it follows up the sale by insisting on excellent pilots and on excellent service organization and by giving, I believe, very good service to its customers. The company sells to sportsmen. The fact is that this company sells airplanes, at something like $20,000 each, to people who have no accidents, are apparently satisfied and are likely to be repeat customers. Let us sell the airplane as a sporting proposition in the way that it should be sold, independently of all Government support.

In selling the airplane on an industrial basis, I believe that any business man in the United States can be interested in aviation. Let us go to certain specific industries and show them that the airplane can be used for a definite commercial purpose. For instance, I have been associated with some people in selling a man an airplane in which he is going to go from one lobster fishery to another to perform his tour of inspection rapidly and efficiently. He figured that he would save money in that way, and that was the great point to bring home to him.

A company in New York City is selling photographic service and it is doing a large volume of business. In all the great cities of the United States, photographic companies are already in existence to which the airplane might be sold for this specific purpose. Paper manufacturers own vast forests. We can go to them and explain how they can safeguard their forests by the use of airplanes. We can point out how much an airplane will cost, how it can be used and how to get pilots. Such industries will buy airplanes and use them as they are being used in Canada today, where one particular company has 25 forest-patrol airplanes in operation. If we go right through the industries and use a little real salesmanship in the way that the motor-car people have done, we may get there.

FRANK H. RUSSELL:—I want to get some information from Mr. Wallace for the advantage of those who may not have it. First, were the drawings, specifications or bills of material that he speaks of guaranteed by the United States Government for the building of those 20 machines? Second, were the 20 machines built by another than the original producer or designer?

MR. WALLACE:—The original machines to which I re-

ferred were Martin bombing airplanes. Work was begun on July 1 and the 20 machines were finished June 15 of the following year. I know that about 100 typographical errors and mistakes in the specifications have been corrected and reported to the Air Service. It is very difficult at times for a company to fall in line with another company's limits. The Government saw the necessity of having certain limits and making all fits free, so that the parts could go together if made in different sections of the country.

MR. RUSSELL:—Did the United States Government guarantee those drawings?

MR. WALLACE:—I do not think that the Government or the Air Service could guarantee another company's drawings.

MR. RUSSELL:—Did it offer them to the industry for public bidding without making any guarantee as to their accuracy?

MR. WALLACE:—I do not think it could guarantee the drawings for it had not proved them. The only way it could prove them was to let another company use them. It might eventually guarantee them after that.

MR. RUSSELL:—On the contrary, the Government did so offer the drawings. The machines were produced by the original designer as a proprietary article and very successfully; but when the drawings were put into another factory without the guarantee of the Government on a public bid, the first company building that machine spent $50,000 on engineering work before it completed the first airplane. Mr. Wallace has confirmed rather than contradicted my statements. The Martin bombing airplanes were offered to public bid, contracts were placed and the contractors assumed an unknown risk. The Martin bombing airplane was considered a commercial article and yet the Government itself could not vouch for the drawings from which it was constructed.

MR. WALLACE:—It is necessary to note the following to understand the expense of $50,000. The company had a contract for 50 machines. Many alterations of design were involved that may have cost the builder much more than it would have cost the other company that produced the drawings of the original machines.

THE DESIGN OF COMMERCIAL AIRPLANES

BY E. P. WARNER

THE author discusses commercial-airplane design in general terms, considering the subject under the main divisions of economy, safety, speed and comfort. Under economy, mention is made of possible reductions of first cost by designing for long life and reliability, the effect of the former on the depreciation allowance being obviously advantageous. Airplane size is debated also, the trend of progress being seemingly toward the giant airplane.

Safety is stated to be dependent upon reliability, structural strength, stability, control, fire prevention and reduction of risk of injury to passengers in the event of a crash. Minimizing the results of a crash is considered suggestively.

Speed is governed almost solely by the ratio of wing loading to power loading; hence, speed will always be kept as low as possible without loss of business to competing transportation enterprises. Among desirable measures to secure comfort, adequate ventilation and the elimination of noise are included. [Printed in the February, 1923, issue of THE JOURNAL.]

THE DISCUSSION

ARCHIBALD BLACK:—Commercial aviation is a subject to which I have given fully half of my time during the past 3 years. Consequently, I have followed Professor Warner's paper with great interest and feel that he has shown a very clear appreciation of the problem of airplane design in all of its details.

The problem of economical operation, which also includes that of safe operation, is the one outstanding point in design considerations. It appears inadvisable to count upon subsidies other than payment for carrying mail, at least in the United States. In this connection the specifications attached to some foreign subsidies might prove very misleading as regards the requirements of commercial airplanes. Some of the French specifications, particularly, suggested the intention of overnight conversion of supposedly commercial airplanes into military use.

As to the matter of speed, I am in general agreement with Professor Warner's remarks, but consider his suggestion of 85 m.p.h. rather low. In my paper entitled The Influence of Design on the Cost of Operating Air-

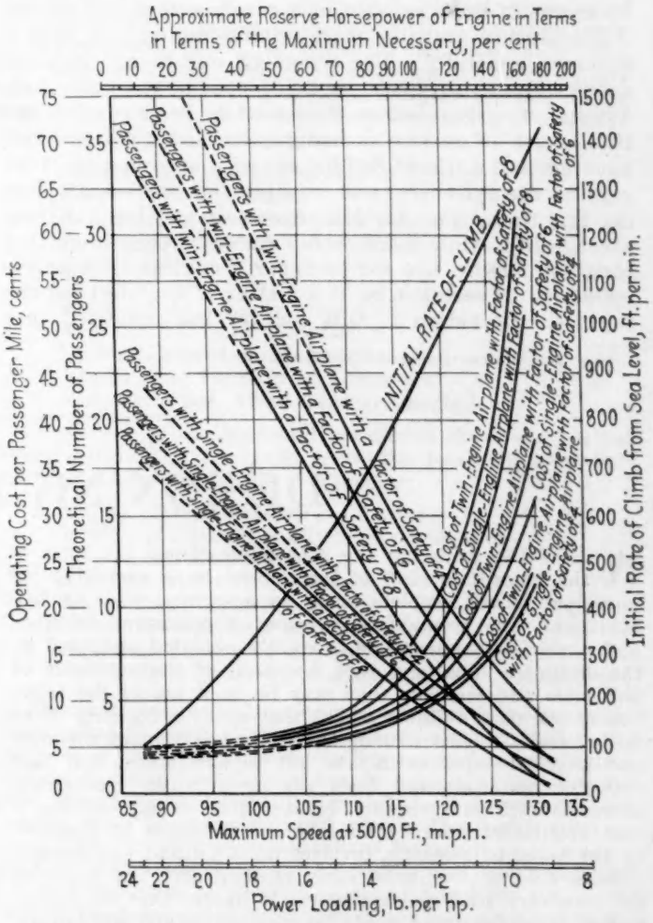

Approximate Reserve Horsepower of Engine in Terms of the Maximum Necessary, per cent
0 10 20 30 40 50 60 70 80 90 100 120 140 160 180 200
Operating Cost per Passenger Mile, cents
Theoretical Number of Passengers
Initial Rate of Climb from Sea Level, ft. per min.
INITIAL RATE OF CLIMB
Passengers with Twin-Engine Airplane with a Factor of Safety of 8
Passengers with Twin-Engine Airplane with a Factor of Safety of 6
Passengers with Single-Engine Airplane with a Factor of Safety of 8
Passengers with Single-Engine Airplane with a Factor of Safety of 6
Cost of Twin-Engine Airplane with Factor of Safety of 8
Cost of Twin-Engine Airplane with Factor of Safety of 6
Cost of Single-Engine Airplane with Factor of Safety of 8
Cost of Single-Engine Airplane with Factor of Safety of 6
85 90 95 100 105 110 115 120 125 130 135
Maximum Speed at 5000 Ft., m.p.h.
24 22 20 18 16 14 12 10 8
Power Loading, lb. per hp.

FIG. 1—CHART SHOWING THE VARIATION OF THE COST OF OPERATION, THE RATE OF CLIMB AND THE NUMBER OF PASSENGERS WITH THE SPEED AND THE RESERVE HORSEPOWER

These Curves Are for a Series of Single and Twin Liberty Engined Passenger Airplanes of a Constant Minimum Speed of 57 M.P.H. and a 4-Hr. Duration of Flight. The Dotted Portions of the Curves Indicate the Capacity above the Practical Limit. The Weight of the Passengers, Including Baggage, Is Assumed as 190 Lbs.

planes,[1] I considered in some detail the effect of designed performance upon the cost of operation of airplanes. Fig. 1 is taken from this paper and shows the relation between the operating cost and the speed for a series of airplanes. It is wholly practicable to increase the high speed of the machine to 105 or even 110 m.p.h. at a 5000-ft. altitude before the operating cost begins to increase seriously. This enables us to fly normally at 90 to 100 m.p.h. at this altitude. Considering Professor Warner's figure of 85 m.p.h., this possibly would fall to 80 m.p.h. at the operating altitude of about 5000 ft. Fast railroad trains make about 45 m.p.h.; thus, by the time we allow for the trip between the city and the landing-field at each end and for the intermediate stops, the margin of saving becomes rather close. We must sell our transportation upon the basis of speed and at a higher rate.

I agree fully with the remarks regarding the question of maintenance, but would also lay stress on the practicability of utilizing existing types. Metal construction, fabric substitutes and the like are still very much in the experimental stage, and we cannot expect commercial aviation to carry the cost of developing these until it first gets on its feet. In the meantime, it seems probable that they will be developed anyhow for military purposes. As it stands now, we are getting sufficiently good performance out of existing types of *commercial* airplanes to make use of these conventional constructions practicable. Airplanes are probably more reliable and sturdy than is assumed generally. The wings of our much criticized fabric-covered airplanes can be counted upon to give fully 500 hr. of service before they need to be recovered, and this length of service is being increased. We can rely upon getting a life of 800 hr. out of a good engine if we regrind the cylinders, and possibly the crankshaft, during this time. The Air Mail Service is getting a 400-hr. average life, while Aeromarine Airways, Inc., is getting about an 800-hr. life out of Liberty engines *without regrinding*. It seems to be all a matter of how we treat the engines. Operation in this country has indicated that the engine will give excellent service if overhauled on an average of once for every 100 hr. of flying. Of course, engine depreciation remains a very large item in operating cost, and every effort should be made to reduce it, but it is getting down to being within reason. Only recently, aside from the cost of getting business, it was the largest item in our costs, as new engines of commercial sizes range around $16 to $20 per hp.

Regarding airplane size, there is a certain intermediate size that is now the most economical. With the further refinements possible in the larger craft, this size will move upward, but it is obvious that we cannot perpetually evade the "square-cube" law as we might a city ordinance. We will eventually reach the size where no further refinement is possible, whereupon our "economical size" will have become permanent. Where this will bring us, we cannot tell today. Neither need we care to any extent. Our present problem is that of filling the existing sizes sufficiently to justify their operation on a close headway. In this matter of size, however, I feel that the additional safety obtainable through the provision of two pilots would justify some departure from the present economical size.

The suggestion of using two different sizes of airplane is interesting. It seems to me, however, that it is not important so long as we are operating relatively small sizes of craft. As the size of airplanes increases in the future, this probably will become important.

I agree most heartily with Professor Warner's comments on the matter of silencing engines, and feel that this subject is not getting the consideration that it deserves. I have always advocated the silencing of engines of commercial airplanes. It is true, as mentioned, that we still have other noises, but why not get rid of as much of the noise as we can? Any person who has made only one or two flights will give the "terrifying racket" of the engine as his clearest impression. This noise actually has a terrifying effect upon the layman, and is worth reducing if only for its psychological effect on the passengers.

[1] See *Mechanical Engineering*, December, 1922, p. 821.

DESIGNING MOTOR CARS

A MOTOR car is not the conception of one brain, or of the immediate staff of the builder, even excluding the units purchased complete, such as magnetos, tires or ball bearings. The accumulated wisdom of engineers, chemists and physicists innumerable is rightly accepted and used by the designer. The very fact, however, of the profusion of materials and methods that may be used makes the selection of the most suitable a task that needs a training of no mean order. Even assuming that the more complex chemical and physical experiments are left to specialists, and that orthodox materials and fuels are used, purely mechanical problems such as springing, balancing or cooling call for a vast amount of work. This labor, if it cannot be dignified by the name of research, involves much patient exploration.

Some leading companies early realized this, and provided the necessary staff and apparatus to assure that the education of their designers would be progressive and continuous. A few standardized their design so that designers were unnecessary. Most firms, however, produce a new or modified design about every 3 years, so that work must be carried on in order that the new model may be an improvement on the old, either in lower cost or in increased value to the user. At some period a decision has to be made on fundamental design questions, such as high-speed or low-speed engines, sleeve or poppet valves, center or side change; and the functioning of the "designing machine" at these crucial moments may have either a very favorable or a decidedly adverse effect on a firm's reputation.

There are many ways of producing a motor car, more than one way of producing a cheap motor car, but few ways of producing a good motor car cheaply. Even in the hurly-burly of keeping abreast of contemporary design, a large staff is necessary to carry out drawing-office and experimental work, yet this shows no immediate improvement in the profit and loss account. If anything new be contemplated, such as magnetic brakes, supercharged engines or a novel transmission, very many experimental sprats must be thrown to catch the production mackerel.

Modern mechanism is too complex to be evolved from the inner consciousness of any man, however brilliant. Neither does a new constructional method often arise by some flash of genius. Such things are built up step by step, with many false turnings and fresh starting points.—*Automobile Engineer* (London).

Simplification Conference Committee

United Interests of Automotive Industry Pledged to Foster Automotive Engineering Standards at Session Held at United States Department of Commerce

"EVERY great structure requires the process of time. The new and the difficult are always being worked over in the universal consent of common-sense." The Society has been working on automotive engineering standardization problems for over 12 years. The fundamental merit behind the idea of "standards" is generally accepted. No standard can ever be adequate for 100 per cent of the applications into which it might enter but obviously the benefits that accrue from general or near-universal use are not to be sacrificed. It is about axiomatic that so long as the product of one manufacturer meets that of another the details of the juncture should be standardized. Every one concerned in the production or use of apparatus is benefited by its rational standardization.

To formulate and establish successful standards, it is necessary to have cooperative action and mutual concession among all interests. Some standards are, of course, of such public interest that laws requiring their adoption are passed. The process of automotive standardization has been in effect in this Country for 20 years. The Society is committed to the policy of evolution as opposed to any ideal classification or scheme. To standardize some things in all industries is possible. To standardize all things in all is impossible.

It is too easy to think and say that the customer pays and that therefore standardization does not matter to the manufacturer. Standardization is a method of avoiding reprehensible waste. An object of standardization is to express what is good practice, by the definition of terms and the specification of properties and dimensions. The slogan is, do the best possible, but do something; and make changes where necessary. Unnecessary sizes should not be involved in manufacturing. Products should be improved and reduced in cost.

It is not an object or an effect of standardization to make all apparatus out of the same mold, but to bring together the experience of the best qualified men for the purpose of securing better materials, broader outlook in the work as a whole and satisfactory service. It economizes building operations without interfering with the engineer's ability. It increases competition. It makes possible uniformity in material and of important dimensions involving interchangeability, the user benefiting in that he can secure replacements quickly and at less cost, service being maintained with less investment. There is no advantage to any single company in not participating in the establishment and practice of rational standardization. Neither is there any advantage in the way of design. In worldwide trade, as well as in domestic trade, it is obvious that the maintenance of standardization that will make possible the interchangeability of many materials, parts and accessories, is economically requisite. There is no doubt that S. A. E. Standards have lowered greatly the cost of production of automobiles and enabled manufacturers to market their product at lower figures than would have otherwise been possible. The current models show more resourcefulness in design than ever before, while standardization of their component parts has increased.

The need for extending the work of standardization in scope and intensity is becoming realized more in an effective sense in that the whole-hearted attention and cooperation of leading executives in the industry are being had. The full benefits of standardization cannot be secured in the face of executive opposition or their listless acquiescence. The big stake involved necessitates that all the interests shall pull together. The satisfactory solution of the service problem can be hastened greatly by a greater observance of standardization. As has been said, common-sense is merely a substratum of experiences out of which judgments flow. Each and every interest must "cog-in" with all other interests that are cogs in the operations of the whole industry and body of users. Standardization accomplishments to date represent the heart and brain of automotive engineers as a whole.

Commerce Department Meeting

A meeting held in the city of Washington last month under the auspices of the Department of Commerce was attended by official representatives of practically all of the national automotive associations and representatives of some effective local organizations such as the automotive electric service associations located in various cities. After discussion throughout the day, a resolution was passed to the effect that a committee, to be styled the Simplification Conference Committee, of not less than 11, should be appointed to assist the Society of Automotive Engineers in "selling" the standards now in existence, and in solving problems of simplification to be defined. M. L. Heminway, general manager of the Motor & Accessory Manufacturers' Association, was named chairman, and C. E. Quinn, of the Automobile Body Builders' Association, was designated as secretary of the committee. The following organizations, in addition to the Society and those named above, have been asked to nominate representatives on the Committee:

National Automobile Chamber of Commerce
Motor Truck Industries
National Automobile Dealers' Association
Automotive Equipment Association
Automotive Electric Association
American Gear Manufacturers' Association
American Automobile Association
National Hardware Association
Rubber Association of America
Aeronautical Chamber of Commerce
Motorcycle and Allied Trades Association.

In addition to the organizations named above and several representatives of the trade press, the following were represented at the meeting in Washington:

United States Chamber of Commerce
Bureau of Foreign and Domestic Commerce
Bureau of Standards
American Railway Express Co.
Motor Truck Association
Motor Transport Corps of the Army
American Society of Agricultural Engineers
Automotive Metal Wheel Manufacturers' Association

Chairman Heminway, in communicating with the organizations asked to designate representatives, stated that it is the purpose of the committee to supplement and assist existing standards committees for the benefit broadly of the industry and the users of automotive vehicles. It is expected, of course, that the committee will receive thoroughgoing support from the various organizations inasmuch as it is clear that the education of all in the possibilities and necessities of wide reduction to practice of sound standards should result in much improved conditions in the servicing and maintenance of automobiles. It is essential that the public, as well as the dealers, have a clearer understanding of the need and functions of standards.

As has been announced in THE JOURNAL, the following subjects were selected some time ago for promulgation under the methods of the Department of Commerce, by the Simplified Practice Committees of the Society and the Na-

tional Automobile Chamber of Commerce, of which J. G. Vincent and F. E. Moskovics are chairmen respectively:

Roller Bearings
Storage-Batteries
Pneumatic Tires
Spark-Plugs

William A. Durgin, chief of the division of simplified practice of the Department of Commerce, in addressing those attending the Washington meeting, showed by submission of data collected by the Department that the lack of standardization is the principal cause of waste in industry. He stated emphatically that simplification would reduce users' first, accessory and maintenance costs, the decrease in the number of sizes enhancing quality and also the profit to all concerned. He said that there is nothing more constructive in the automotive industry than the S. A. E. HANDBOOK. He urged that this be given publicity and in general that the best thought of the industry be supported. The Department's method of dissemination of information in this connection is the issuance of pamphlets setting forth practices approved by industry, the Bureau of Simplified Practice advising that the standards in question be made universal. He made it plain that the Department of Commerce can do nothing in this respect unless the automotive industry makes specific recommendations. He explained that R. M. Hudson, of his Division, would assist the work in every way possible so far as the Department of Commerce is concerned.

C. C. Hanch, vice-president of the National Automobile Chamber of Commerce, asserted that further standardization work should be done in the tire and other automotive fields. He expressed the opinion that the human side of the whole problem should be studied and the men who pay the bills and sell in the field have a plan of coordination and cooperation. At present the service manager does the best he can when the factory engineering and production departments with which he is connected do not work as effectively together as they should. The large dealers are a very potent influence in the situation. He commended very highly the standards work of the Society, pointing out that it had carried on practically all of the work involved; not being supported sufficiently and perhaps being to blame for this itself. He advised concentrating on the things that affect directly the use of cars, stopping short of those matters that have to do with individuality and style and the necessary catering to personal tastes.

A. J. Grimm, chairman of the standards committee of the Automotive Equipment Association, explained current and proposed methods of that association in propagating the standardization idea in its connections with both car builders and jobbers, a large part of this work being devoted to the explanation and recommendation of S. A. E. Standards.

A. D. T. Libby, president of the Automotive Electric Association, argued that in the solution of the big standardization problems involved it will be necessary to enlist adequate support from leading executives of the motor-car industry, upon whom rests an obligation to ascertain why automotive equipment standards, for example, are not used to a greater extent. The number of parts now needed for servicing is tremendous and without the direct assistance of the executives the fight will be a long uphill one. He explained the effort that is being made by the Automotive Electric Association to establish standard capacity-ratings of electrical generators.

E. E. LaSchum, in charge of motor-truck transport for the American Railway Express Co., said that standardization had resulted in great benefit in such work as his, there being considerably more interchangeability of parts than is generally understood. He said that the cost of the stock of maintenance parts of his company is less than $42 per truck. He expressed the opinion that for reliability of performance the motor truck is unexcelled.

Col. Edgar S. Stayer, U. S. A., stated that if this Country should engage in war under present conditions it would be necessary to stock 250,000 different articles for replacements in motor vehicles, not including accessories and tires. The Government is still confronted with an unjustifiable diversity of repair parts. The present Army maintenance stock costs $60 per truck. Standardization is approved by the War Department, which desires especially consideration of emergency conditions. The more exactly alike the various elements are, the better the conditions will be. Commercial trucks are good and will do what they were designed to do, but must be handled properly.

Clyde Jennings, editor of *Motor Age*, said that at present owners do not know where to purchase replacement parts for their cars, and in addition that the flat-rate system of maintenance is of the greatest assistance in reaching a proper standardization basis. He feels that in the end the maintenance man will control the situation. In most towns at present not more than one or two makes of storage-battery are available for purchase. There are a great many specially made batteries for cars and the size and installation of the batteries are not considered adequately in car design. The inside dimensions of batteries are well standardized but not the outside dimensions. In conclusion, Mr. Jennings urged strongly that the people who control the whole situation be properly educated.

James Dalton, editor of *Automotive Industries*, said that general preaching is not effective in standardization. Standardization is "approved" in general, but in factory purchases immaterial sixteenths are insisted upon. To an undue extent standardization is fine theoretically "for the other fellow." The manufacturers must be sold on the application of standards. Talk will do nothing. His view was that one or two specific things should be concentrated upon for accomplishment within the year. The trade press wants some such definite aim outlined.

D. C. Fenner advised holding joint meetings of executives and engineers to discuss the whole matter.

R. W. Trullinger, of the American Society of Agricultural Engineers, stated that there is inadequate encouragement and development of research work in the tractor industry; that much engineering knowledge is to be acquired and that the engineers do not receive proper support.

Norman G. Shidle, managing editor of *Automotive Industries*, said that a sales organization is needed for the standards work and proposed that the meeting select a committee to assist the Society in coordinating the standards work as a whole, chiefly in the direction of further reduction to practice.

WEAR OF STEELS

SEVERAL tests have been conducted by the Bureau of Standards to determine the resistance to wear of hardened and tempered chromium steels. It was noticed that while the so-called standard hardened specimen, which was run on the upper shaft of the testing apparatus, invariably had a polished surface at the conclusion of every test, the bottom specimen, especially when tempered, presented a dull appearance that was presumed to be caused by abraded particles sticking to the specimen. It seemed, therefore, that specimens with this dull mottled appearance would show a loss of weight less than the actual loss. To prove this several tests were made of Ketos steel running the standard hardened specimen on the lower shaft and the tempered specimens on the upper shaft. The curve of the rate of wear plotted against the tempering temperature was similar to the previous curve but showed a greater rate of wear.

The tempered specimens under the last-named conditions were free from abraded material at the end of the tests. Efforts will be made to prevent the adherence of the abraded metal particles to the specimen.

Laws Governing Gaseous Detonation

By THOMAS MIDGLEY, JR.[1] AND ROBERT JANEWAY[2]

ANNUAL MEETING PAPER *Illustrated with* PHOTOGRAPHS AND CHARTS

THE authors present in this paper an explanation of gaseous detonation based upon what are considered incontrovertible laws, and show by the functioning of these well understood natural laws that gaseous detonation is a phenomenon that does not require any hypothetical assumptions to account for its existence.

The physical conditions that must exist within an enclosed container when it is filled with an explosive mixture of gases and these gases are ignited are stated and analyzed mathematically, and an application of this analysis is made to the internal-combustion engine. The apparatus and the procedure are described, inclusive of photographs and charts, and it is shown how the formulas can be applied (*a*), for constant throttle and varying the temperature of the entering charge and (*b*), for constant temperature and varying the throttle opening and the compression-ratio. The results are illustrated and discussed in some detail.

Appendix 1 refers to the basic equations in the paper and has as its object the combination of these equations

$$P_1 - P_2 = W^2/g\ (V_2 - V_1)$$
$$W = KD_1^n T_1^m$$

into a single fundamental expression containing P_1 and P_2 as the only variables.

Appendix 2 is a mathematical determination of the critical pressure of detonation.

THE phenomenon of gaseous detonation has been recognized for many years. As early as 1888 it had been studied extensively by Bertholet and Le Chatelier of France and also by Harold B. Dixon of England. Since that time many other investigators have studied this phenomenon, as well as studying the normal combustion of gases as it occurs under varying conditions. Unfortunately, up to the present, investigators of gaseous detonation have been so busy collecting data that no one of them has taken the time to investigate the phenomenon from a theoretical standpoint, or to explain it upon the basis of sound fundamental laws. Gaseous detonation has, therefore, remained comparatively unexplained. It is our belief that, if a phenomenon can be explained fully by known and proved laws, there is no justification for any explanation based upon unsubstantiated assumptions. Therefore, we desire to present in this paper an explanation of gaseous detonation based upon what are considered to be incontrovertible laws, and to show by the functioning of these well understood natural laws that gaseous detonation is a phenomenon that does not require any hypothetical assumption to account for its existence.

First, let us determine what physical conditions must exist within an enclosed container when it is filled with an explosive mixture of gases and these gases are ignited. Fig. 1 represents what would be a series of instantaneous photographs of flame-travel within a cylinder, were it possible to make such photographs. These diagrams are not assumptions, but are based upon actual observations

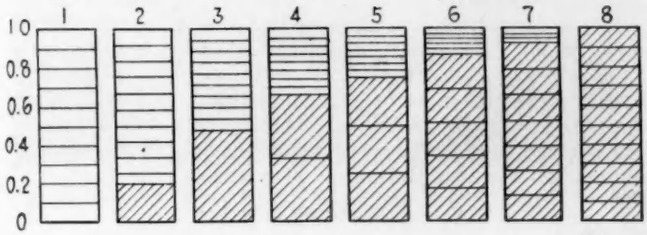


FIG. 1—DIAGRAM ILLUSTRATING FLAME TRAVEL IN A CYLINDER

by Woodbury, Lewis and Canby, in their paper on The Nature of Flame Movement in a Closed Cylinder,[3] and a mathematical analysis thereof made by Thomas Midgley, Jr., on Molecular Movements During Combustion in Closed Systems.[4] Diagram No. 1, in Fig. 1, represents a bomb filled with a combustible gas mixture with division lines between each one-tenth portion of this mixture. No. 2 represents the partial combustion of the first one-tenth. No. 3 represents the total combustion of the first one-tenth and Nos. 4, 5, 6, 7 and 8, represent successive stages of the process. It will be observed that by the time the first one-tenth of this gas has burned, it has expanded as indicated in No. 3 and thereby compressed ahead of it the remaining nine-tenths of unburned mixture. Also, it will be observed in No. 4 that, as the second one-tenth burns, it is not only compressing the gas ahead of it but likewise the gases to its rear. If the positions of the various particles as they move along the bomb are plotted against time, we will obtain a diagram such as that shown in Fig. 2. This chart is called a displacement diagram because it shows the displacement of the particles from their initial positions within the bomb. If now we follow

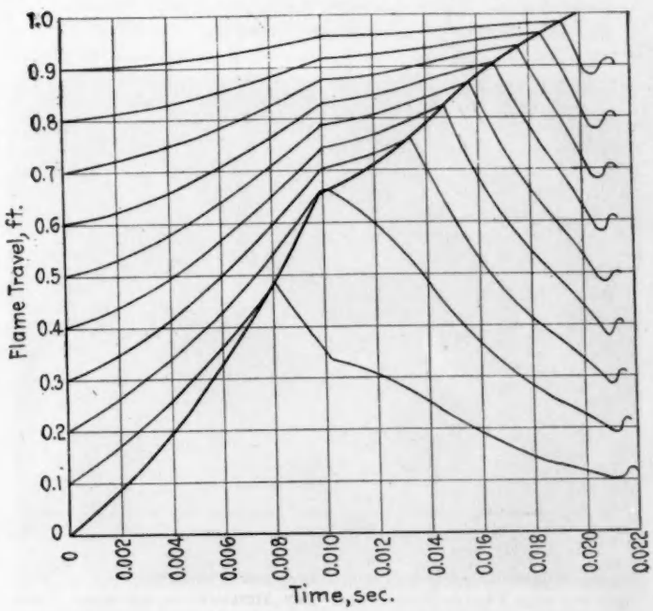


FIG. 2—DISPLACEMENT DIAGRAM OF THE PARTICLES DURING TOTAL COMBUSTION

[1] M.S.A.E.—Chief engineer, fuel section, General Motors Research Corporation, Dayton, Ohio.

[2] Mathematician, fuel section, General Motors Research Corporation, Dayton, Ohio.

[3] See THE JOURNAL, March, 1921, p. 209.

[4] See THE JOURNAL, May, 1922, p. 357.

the behavior of a single particle such as the one that is two-tenths of the way up the bomb, before ignition, it will be observed that just before the flame-front overtakes this particle it has an upward velocity with respect to the bomb and that, just after the flame-front has passed through it, the particle has a rearward velocity with respect to the bomb. Since this particle has mass and has had its velocity changed, one of the most fundamental laws of physics dictates that there must have been a force acting in the direction of this change of velocity. Now the only force that can be operating in a space containing gases alone is a pressure difference within these gases themselves. Therefore, it is obvious that a slightly greater pressure must exist ahead of the flame-front than behind it. From the fundamental law that force equals mass times acceleration, we can derive a mathematical expression for this difference of pressure. It is:

$$P_1 - P_2 = W^2/g\ (V_2 - V_1) \qquad (1)$$

where

$g = 32.2$
P_1 = the pressure ahead of the flame-front, in pounds per square foot
P_2 = the pressure to the rear of the flame-front, in pounds per square foot
V_1 = the specific volume of gases, in cubic feet per pound, corresponding to P_1
V_2 = the specific volume of gases, in cubic feet per pound, corresponding to P_2
W = the weight of the gas, in pounds, that enters the flame-front per second

In the above equation, it is obvious that the magnitude of the pressure-difference is dependent upon W, the weight of gas entering the flame-front per unit of time. Therefore, we can continue our analysis profitably by investigating the nature and the factors that control W.

In physical chemistry, the weight of gas entering the flame-front per unit of time is known as the reaction-velocity. Physical chemists have done a great amount of work in establishing laws with regard to reaction-velocities. For this case, the following equation has been proposed:[5]

$$W = K \times D^n T^m \qquad (2)$$

where

D = the density, or concentration
K = a constant to be determined experimentally.
n = an exponent to be determined experimentally
m = an exponent to be determined experimentally
T = the absolute temperature

As an alternative to this treatment of W, we can substitute $W = KD^nC^T$; where C is another constant to be determined experimentally. However, this becomes decidedly ponderous in the further development, and does not appear to be any more accurate than the treatment selected. Both expressions appear to be close approximations, neither being absolute. For example, n should be a whole number and probably would be were the treatment of T perfect; otherwise, n will vary so as to compensate for the error in the treatment of T. The treatment we have selected gives n a value of 0.9 and, using the alternate method, we obtain for n a value of 1.1. The mean of these two values gives n equal to unity, which is probably correct. Since no accepted treatment of T gives n this value, the treatment that is most easily handled mathematically has been selected.

To return to the discussion proper, it will be observed that the equation $W = KD^nT^m$ applies to conditions obtaining in the immediate front of the flame-front, and not to the conditions to the rear of the flame-front. In other words, $D = 1/V_1$ and T is the temperature corresponding thereto. Thus it is obvious that the pressure-difference depends mainly upon W; and that W, in turn, is a function of the pressure ahead of the flame-front.

To make clear the above relationships let us consider an actual case substituting numerical values. Our equations are

$$W/g = LP_1^Q \qquad (3)$$

where

$Q = 3$ (See Appendix 2)
$W = BP_1^{1.8}$
$B = 0.061$

$$P_1 - P_2 = (W^2/g) \times (C/P_2) \qquad (4)$$

where

$C = 835$ (See Appendix 1)

When $P_1 = 252$ lb. per. sq. in. absolute, by substitution in (3) we have

$$W = 0.061 \times (252)^{1.8}$$
$$= 241 \text{ lb. per sec.}$$

Substituting in (4) we have

$$144\ (252 - P_2) = (241/32.2) \times (835/P_2)$$

solving

$P_2 = 200$ lb. per sq. in. absolute
$P_1 - P_2 = 52$ lb. per sq. in. absolute

[5] See Physical Chemistry for Colleges, by Millard, pp. 303 and 310; see also Chemical Statics and Dynamics, by Mellor, pp. 383 to 393; see also Theoretical Chemistry, by Nernst, (10th German edition) pp. 750 to 754.

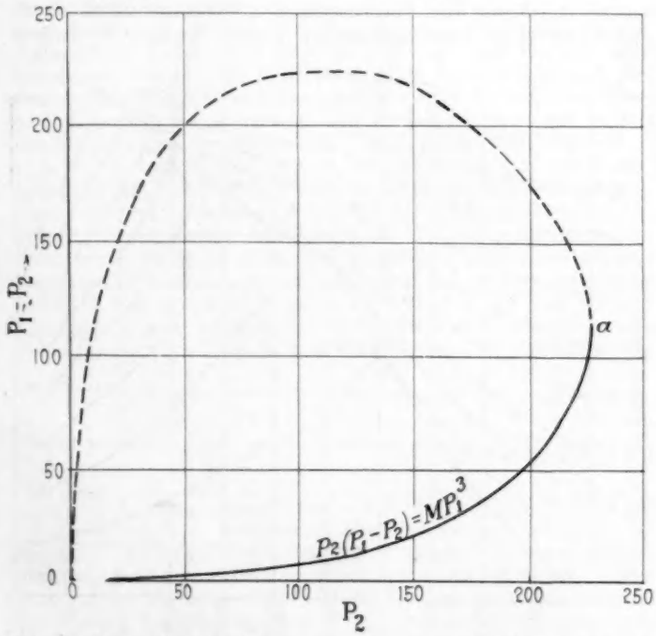


FIG. 3—CURVE OF THE RELATION BETWEEN THE PRESSURE IN THE REAR OF THE FLAME-FRONT AND THE DIFFERENCE BETWEEN THIS PRESSURE AND THAT AHEAD OF THE FLAME-FRONT DURING THE COMBUSTION PROCESS

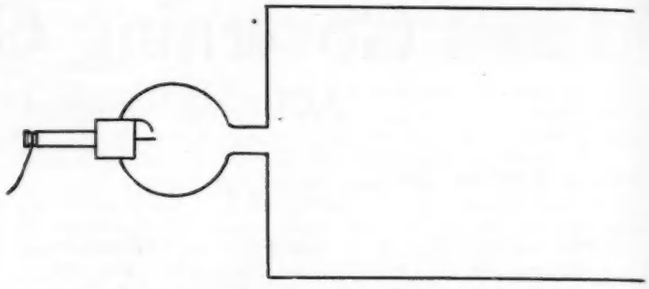


FIG. 4—APPARATUS EMPLOYED TO VERIFY THE MATHEMATICAL ANALYSIS OF PRESSURE RELATIONS IN COMBUSTION

This value is an actual point used in plotting the curve of Fig. 3.

It will be expedient, therefore, to combine these two equations into one expression. Appendix 1 gives the mathematics involved in deriving and simplifying this expression.

In its final form it becomes—

$$P_1 - P_2 = (MP_1Q/P_2) \qquad (5)$$

If now some definite values are assigned to M and Q and this expression is plotted, a curve as given in Fig. 3 is obtained.

It is quite obvious that, in the actual phenomenon of combustion, P_2 cannot reduce from the point a but must increase as combustion continues. What actually takes place at this point is a sudden enormous increase in the reaction velocity and hence in the pressure differential. The extent of this increase is governed by some limiting factor or factors other than those already taken into account and irrelevant to the purposes of this paper. Probably the major factor involved is the limiting of the flame travel to the velocity of sound which the rate of transmission of molecular activity cannot exceed.

Before continuing the analysis and applying it to the internal-combustion engine it will be well to consider briefly the result of open-tube experiments in the light of the above analysis. H. B. Dixon, in his paper on the Movements of the Flame in the Explosion of Gases,[6] describes the phenomenon of combustion in an open tube as follows:

> When a mixture of carbon disulfide and nitric oxide was fired near the closed end of the tube, the movement of the flame uniformly accelerated until the detonation wave was set up.
>
> In explosions starting at the open end of the tube, the development of the detonation wave is not progressive but always instantaneous. The detonation wave is characterized not only by its great velocity of movement, but by its intense luminosity and the very high pressures instantaneously set up in it.
>
> Our photographs have shown that the wave of detonation has certain characteristics by which it may be readily recognized: (*a*) it starts suddenly, and (*b*) it travels with constant velocity.

With Dixon's description in mind, note how closely it parallels the mathematical analysis. In Fig. 3, the flame-front has been progressing with a slightly accelerating velocity up to the point a, when its velocity suddenly jumps to a very high value at which it remains constant.

A further experiment verifying the mathematical analysis is described as follows: Fig. 4 represents a short open tube filled with a combustible mixture of gases adapted to be ignited from the small chamber at the left that contains a spark-plug. Upon igniting the charge in this small chamber, a detonation wave will be set up and issue into the large chamber; whereupon the entire volume of gas in the latter will detonate, although its pressure is far below the critical value, a, of P_2. But for any value of P_2 as stated above, P_1 may be infinite. Consequently, if this bulk of gases be ignited by a detonation wave, detonation of the whole will result.

Application to the Internal-Combustion Engine

The application of the foregoing to the internal-combustion engine is not an easy task. In studying gaseous detonation in bombs and explosion tubes, we have the gas in a quiescent state and in regularly shaped chambers with an organized flame-front proceeding through it. We meet, in the internal-combustion engine, turbulence and irregularly shaped combustion-chambers with varying spark-plug locations still further complicating the situation. To take all these factors into account is an almost impossible mathematical task. However, by assuming that in a specific engine these factors affect the constant of the reaction-velocity, the procedure is simplified greatly.

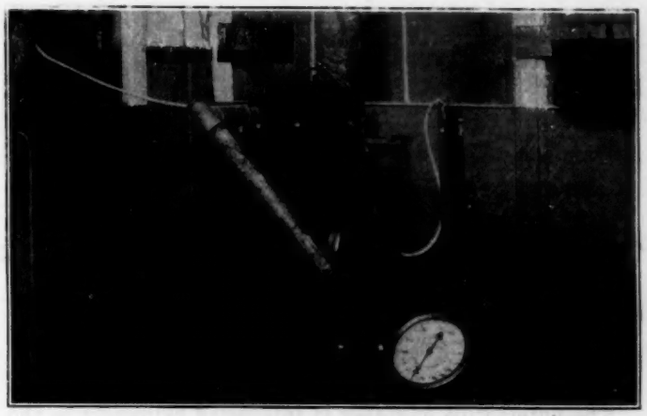


Fig. 5—The Single-Cylinder Delco-Light Plant Used in Making the Experiments

Before attempting to apply the laws governing gaseous detonation specifically to the internal-combustion engine, it may be well to give the reasons for our certainty that gaseous detonation within the engine cylinder is the phenomenon that causes engines to knock.

(1) A high-pressure high-velocity detonation-wave striking the cylinder-head *should* distort it and thereby produce the metallic noise that is called a knock

(2) The luminosity that is observable during gaseous detonation in an explosion tube is also present in the flame within the cylinder when the engine knocks

(3) Anti-knock materials, such as diethyl selenide and tetraethyl lead, could scarcely affect the auto-ignition temperature of a fuel when used in the very small quantities that are necessary to suppress knocking. Apparently, the only way to explain

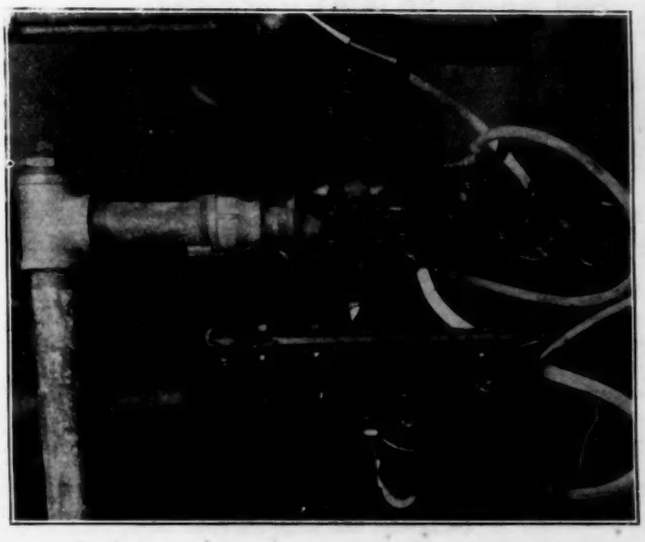


Fig. 6—Looking Down on a Portion of the Engine Used in the Experiments

[6] See *Transactions of the Philosophical Society*, vol. 200, p. 315.

FIG. 7—A SAMPLE INDICATOR-CARD OBTAINED IN MAKING THE EXPERIMENTS

their effect is on the basis that they affect the constant of the reaction velocity of gaseous detonation. Furthermore, these materials will suppress the detonation occurring in explosion tubes to the same degree and in the same manner that they suppress the knock in engines

The automotive engineer is interested primarily in the factors that affect the point at which detonation will take place, rather than in the nature of detonation. Therefore, we will continue our analysis with the object of indicating what factors are important and how their variation affects the critical pressure at which detonation will take place.

If we differentiate P_2 of equation (5) with respect to P_1 and equate to zero, as shown in Appendix 2, we obtain the following expression for the critical pressure of P_2, or the point a in Fig. 3.

$$P_2 = {}^{Q-2}\sqrt{[(Q-1)^{Q-1}]/MQ^Q} \qquad (6)$$

where

C_p = the specific heat at constant pressure of the charge, and can be assumed from existing laboratory data

C_v = the specific heat at constant volume

D_0 = the density, obtained from the running engine

h = the number of British thermal units that can be liberated by the combustion of 1 lb. of cylinder charge, taking into account the effect of exhaust-gas dilution; and it can be calculated when the mixture-ratio, the manifold depression, the compression-ratio and the heating value of the fuel are known

$M = [(K^2 D_0^{2n} T_0^{2m}) / (g \times P_0^Q)]\ [hR/C_p)]$

m = a quantity to be determined experimentally

n = a quantity to be determined experimentally

P_0 = the pressure at the closing of the intake valve, obtained from the running engine

P_2 = the critical pressure of detonation, which can be obtained from an indicator card taken on the engine

$Q = 2[n + m\ (y-1)]/y$

$R = 778\ (C_p - C_v)$

T_0 = the absolute temperature, obtained from the running engine

By taking a sufficient number of readings from the engine and substituting in equation (6), the values of Q, n and m can be determined.

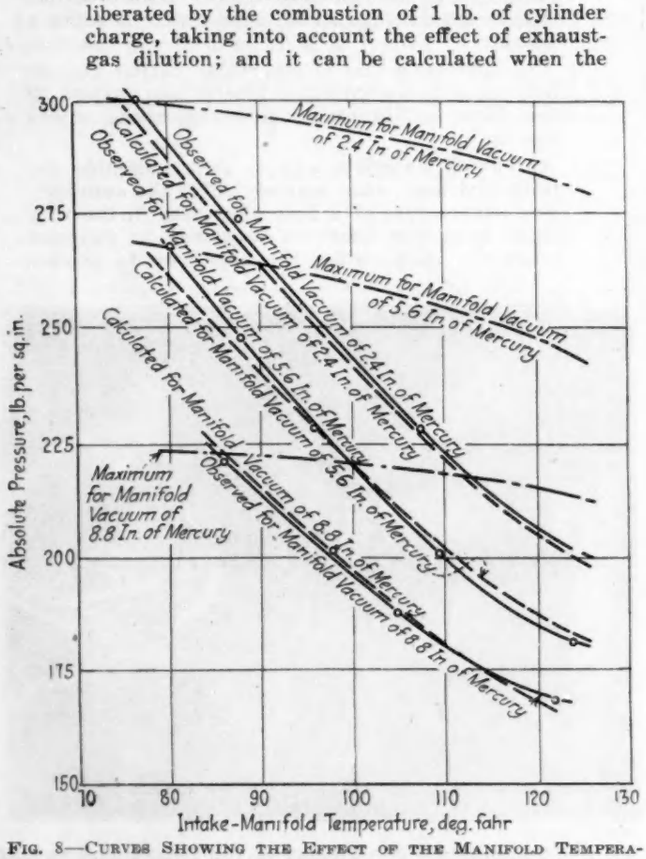

Maximum for Manifold Vacuum of 2.4 In. of Mercury
Observed for Manifold Vacuum of 2.4 In. of Mercury
Calculated for Manifold Vacuum of 2.4 In. of Mercury
Maximum for Manifold Vacuum of 5.6 In. of Mercury
Observed for Manifold Vacuum of 5.6 In. of Mercury
Calculated for Manifold Vacuum of 5.6 In. of Mercury
Maximum for Manifold Vacuum of 8.8 In. of Mercury
Observed for Manifold Vacuum of 8.8 In. of Mercury
Calculated for Manifold Vacuum of 8.8 In. of Mercury
Absolute Pressure, lb. per sq. in.
Intake-Manifold Temperature, deg. fahr
300
275
250
225
200
175
150
10
80
90
100
110
120
130

FIG. 8—CURVES SHOWING THE EFFECT OF THE MANIFOLD TEMPERATURE ON THE CRITICAL PRESSURE OF DETONATION

APPARATUS AND PROCEDURE

The experimental apparatus consisted of a single-cylinder 2 1/2 x 5-in. Delco-Light plant with the generator loaded on rheostats and equipped with a Midgley indicator, as shown in Figs. 5 and 6. The compression-ratio was 4.1 to 1, and this sufficed to produce violent detonation when using kerosene as fuel.

The indicator was used to determine the point of detonation, which was defined by the sudden fading of the light on the pressure-time card because of the rapid acceleration of the indicator mirror. That this point should be considered as P_2 is debatable. It is our opinion that, during engine operation, the combustion is without a well organized flame-front, due to turbulence and the like, and that P_1 exists only over the limited region in the immediate front of the flame. On the indicator-card, this will appear as a part of the rise due to detonation. Fig. 7 shows a sample card with the point of detonation at P.

As a means of measuring the manifold depression directly with a mercury manometer, a small valve, actuated by the inlet-valve rocker-arm, was interposed between the manifold and the manometer. The manometer valve was synchronized with the inlet-valve so as to open only during the time that the inlet valve was open, thus preventing any error in reading due to pressure variation in the manifold. This reading was checked with an intake-manifold indicator and found to be satisfactory. It does not take into account the drop across the intake-valve and, consequently, is in slight error. The manifold temperature was measured with an ordinary thermometer. Although such a means of measurement admittedly does not give accurate results, it is satisfactory for comparative purposes.

TABLE 1—TEST DATA FOR FIG. 8

No. of Run	Manifold Temperature, Deg. Fahr.	Engine Speed, R.P.M.	Manifold Vacuum, In. of Mercury	Critical Pressure, Lb. per Sq. In., Absolute
1	77.0	Constant at 925	2.4	300
	88.0		2.4	274
	107.5		2.4	228
	124.5		2.4	201
2	80.5		5.6	268
	88.0		5.6	248
	96.0		5.6	228
	109.0		5.6	201
	124.0		5.6	181
3	86.0		8.8	221
	97.5		8.8	201
	104.5		8.8	188
	113.0		8.8	177
	122.0		8.8	168

Several runs were made at constant throttle. Beginning at about 25 deg. cent. (77 deg. fahr.), at which temperature in the manifold detonation began, indicator-cards were taken at 5-deg. cent. (9-deg. fahr.) intervals up to 50 deg. cent. (122 deg. fahr.). The speed was maintained constant throughout all runs. Several fuel-consumption determinations also were made during each run, so that the comparative mixture strength might be known. The carbureter adjustment, as well as the spark setting, remained unchanged throughout all the runs.

The data obtained by the foregoing method can now be substituted in equation (6) and the equation solved. The substitutions are omitted for the sake of brevity, but the data are given in Table 1. The values determined experimentally are $Q = 3$; $n = 0.9$; and $m = 3.22$. Thus, the equation becomes

$$P_2 = 0.148/M \qquad (7)$$

where

K = a constant depending upon the nature of the fuel, the speed, the spark setting and the engine design

$M = [(K^2 D_0^{1.8} T_0^{6.44})/(g \times P_0^3)]\,[(hR/C_p)]$

Thus, if the combustion efficiency remains constant, the variables that alone govern the detonation point for any given engine, at a given speed and spark setting, are the initial mixture-conditions of density, temperature and pressure and mixture-ratio. It must be understood clearly that this formula defines merely the maximum pressure that must not be exceeded during combustion under any given set of conditions if detonation is to be avoided. Also, the constant K must be determined experimentally for any particular engine.

The formula can now be applied to the specific conditions that it is desired to investigate. For example, in the engine from which these data were obtained, *for constant throttle and varying entering-charge temperature.*

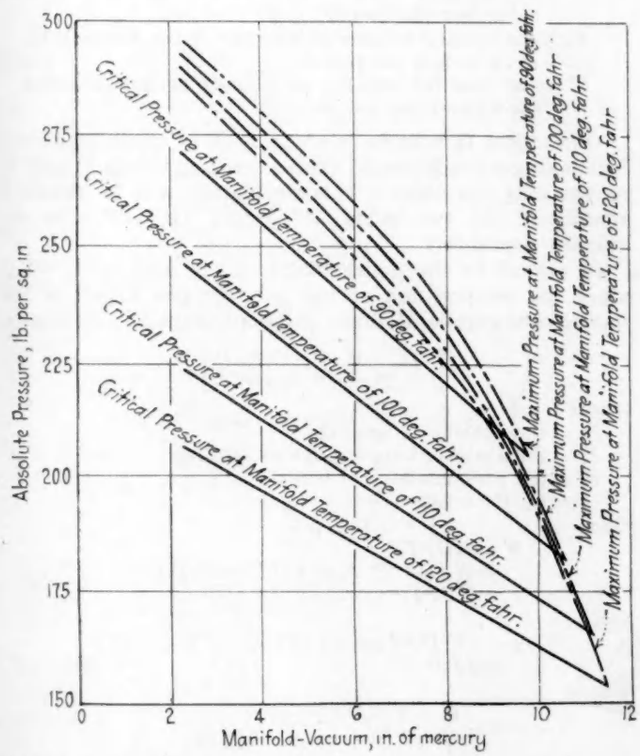

Absolute Pressure, lb. per sq. in
Manifold-Vacuum, in. of mercury
Critical Pressure at Manifold Temperature of 90 deg. fahr.
Critical Pressure at Manifold Temperature of 100 deg. fahr.
Critical Pressure at Manifold Temperature of 110 deg. fahr.
Critical Pressure at Manifold Temperature of 120 deg. fahr.
Maximum Pressure at Manifold Temperature of 90 deg. fahr.
Maximum Pressure at Manifold Temperature of 100 deg. fahr.
Maximum Pressure at Manifold Temperature of 110 deg. fahr.
Maximum Pressure at Manifold Temperature of 120 deg. fahr.

FIG. 9—THE EFFECT OF THE MANIFOLD VACUUM ON THE CRITICAL PRESSURE OF DETONATION IS SHOWN BY THESE CURVES

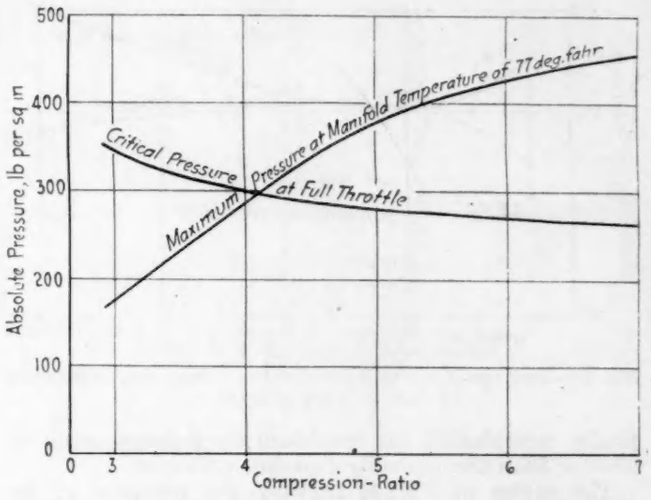

Absolute Pressure, lb per sq in
Compression-Ratio
Critical Pressure
Maximum Pressure at Manifold Temperature of 77 deg. fahr
at Full Throttle

FIG. 10—CURVES SHOWING THE EFFECT OF THE COMPRESSION-RATIO ON THE CRITICAL PRESSURE OF DETONATION

$$P_2 \propto 1/D_0^{1.8} T_0^{6.44}$$

Since $D_0 \propto 1/T_0$ when P_0 = a constant, we have

$$P_2 \propto 1/T_0^{8.24} \qquad (8)$$

This shows the predominating influence of temperature on the pressure at which detonation will occur.

For constant temperature and varying throttle and compression-ratio

$$P_2 \propto 1/[(D_0^{1.8} \times h)/P_0^3]$$

Since $D_0 \propto P_0$ at constant temperature and $h \propto 1 - [\{C\,l\,(P_a/P_0)\}/C\,V]$, the effect of exhaust-gas dilution, where P_a = barometric pressure

$$h \propto 1 - (P_a/rP_0)$$

When r = compression ratio

$$P_2 \propto \frac{P_0^{3.2} r}{rP_0 - P_a} \qquad (9)$$

It is evident from the foregoing two formulas that density serves merely to modify the effects of the determining factors, temperature and pressure.

It should be emphasized that the pressure at which detonation occurs is independent of the compression-ratio, except insofar as it affects the effective heating value by varying the amount of extaust-gas dilution in the cylinder charge. It appears in this connection in equation (9). The compression-ratio really influences knocking to the greatest extent by affecting the maximum pressure attained in the engine.

DISCUSSION OF RESULTS

The curves in Fig. 8 show the variation of detonation pressure with intake-manifold temperature for different throttle positions, the speed and the spark setting remaining constant. Each pair of curves is plotted from the observed data, and the corresponding calculated data, and is accompanied by a curve showing the corresponding variation of final pressure, as calculated. It is obvious that the tendency of the engine to detonate is shown by the relation of the final pressure curve to that of detonation pressure; the point of intersection marks the transition from normal to detonating combustion, the intensity of detonation increasing with temperature beyond this point. It is observed that the point of intersection occurs at slightly higher temperature as the throttle is closed. The observed and the calculated curves are prac-

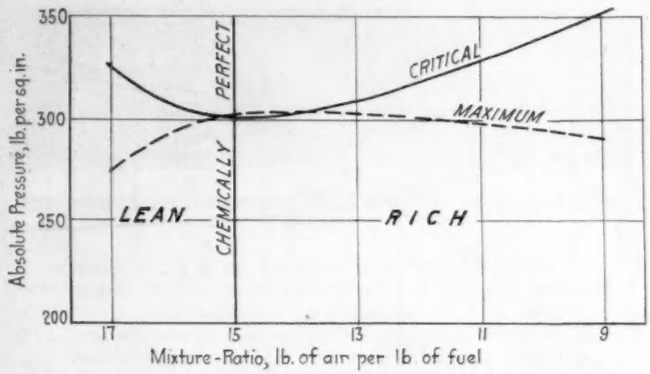


FIG. 11—HOW THE MIXTURE-RATIO AFFECTS DETONATION IS BROUGHT OUT BY THESE CURVES

tically coincidental, the maximum discrepancy being no greater than the probable experimental error.

The curves of Fig. 9, showing the variation of detonation pressure and maximum pressure with manifold depression at various constant temperatures, were plotted from the curves of Fig. 8. The final-pressure and detonation-pressure curves of Fig. 8 converge toward the point of intersection, at which point detonation disappears. As the temperature decreases, the point of intersection can be seen to occur at slightly lower manifold-depressions.

Fig. 10 shows the application of these formulas in calculating the variation of the critical and maximum pressures with change of compression ratio at full throttle at a manifold temperature of 77 deg. fahr. The substitutions in the equation are not included, nor are these results checked by actual runs. To the left of the point of intersection lies the range of compression-ratio for normal combustion; as the ratio increases beyond this point, detonation becomes more and more intense. It is obvious that the above variation is due almost entirely to the increase of maximum pressure with increasing compression ratio.

The curves of Fig. 11 show the calculated variation of critical and maximum pressure with changing mixture-ratio. As in the case of the compression-ratio chart, the substitutions are not included nor are the results checked by actual runs. The mixture was assumed to be chemically perfect at 15 to 1. It is observed that detonation disappears gradually as the mixture gets richer. On the lean side, the available heat of the mixture drops off rapidly, thereby causing a corresponding rapid change toward normal combustion. This curve probably deviates considerably from the actual relationship, due to the fact that the constant of the reaction velocity of combustion undoubtedly is reduced by the presence of excess fuel and also to the fact that the chemically perfect mixture that has been assumed to liberate a maximum amount of energy, probably does not do so, the maximum energy liberation occurring more nearly at 12 to 1 than at 15 to 1. However, the curve shows in a qualitative way the relationship existing between knock and mixture-ratio, and indicates the major factors involved. Fig. 12 records the physical characteristics of the kerosene used in all runs.

[7] A rational expression for this quantity has also been derived but is omitted here because of its complicated nature. The use of the much simpler approximate form has been found to introduce inconsiderable error.

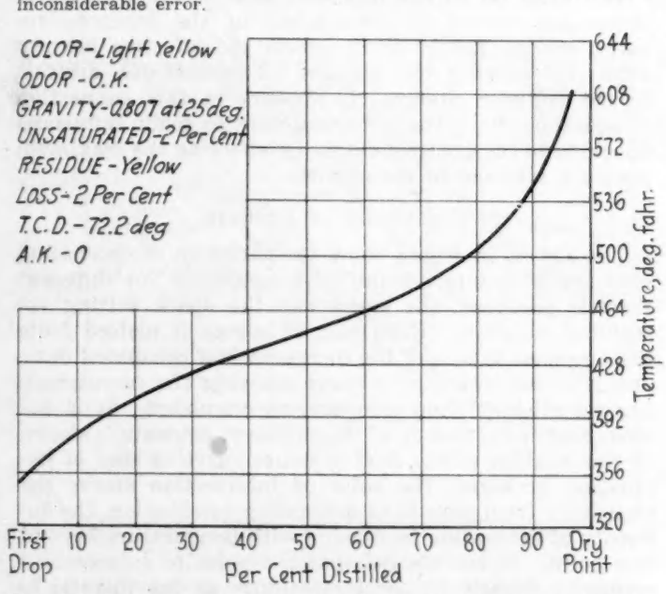


FIG. 12—DISTILLATION CURVE AND PHYSICAL CHARACTERISTICS OF THE KEROSENE USED IN ALL OF THE TEST RUNS

APPENDIX 1.

BASIC EQUATIONS

The basic equations upon which this development depend are mentioned in the text of the paper.

$$P_1 - P_2 = W^2/g\,(V_2 - V_1)$$
$$W = KD_1^n T_1^m \qquad (2)$$

where

D_1 = the density ahead of the flame-front
$g = 32.2$
m = an exponent to be determined experimentally
n = an exponent to be determined experimentally
P_1 = the pressure ahead of the flame-front, in pounds per square foot
P_2 = the pressure to the rear of the flame-front, in pounds per square foot
T = the absolute temperature ahead of the flame-front
V_1 = the specific volume ahead of the flame-front, in cubic feet per pound
V_2 = the specific volume to the rear of the flame-front, in cubic feet per pound
W = the reaction-velocity, in pounds of gas entering the flame-front per second

Our object is now to combine both of these equations into a single fundamental expression containing P_1 and P_2 as the only variables. This derivation will be followed readily if the two parts, W^2/g and $(V_2 - V_1)$ be developed separately.

In regard to the development of the first part, W^2/g, since the compression of the unburnt gas ahead of the flame-front can be assumed to be substantially adiabatic.

$$D_1/D_0 = V_0/V_1 = (P_1/P_0)^{1/y}$$
$$T_1/T_0 = (P_1/P_0)^{(y-1)/y}$$

where

D_0 = the density at ignition
T_0 = the absolute temperature at ignition
P_0 = the pressure at ignition
$y = C_p/C_v = 1.35$

then

$$W = KD_1^n T_1^m$$
$$= K\,[D_0^n (P_1/P_0)^{n/y}]\,[T_0^m (P_1/P_0)^{[m(y-1)]/y}$$
$$= KD_0^n T_0^m (P_1/P_0)^{[n+m(y-1)]/y}$$

and

$$W^2/g = (K^2 D_0^{2n} T_0^{2m}/g)\ (P_1/P_0)^{2[n+m(y-1)]/y}$$
$$= LP_2^Q \qquad (3)$$

where

$$L = K^2 D_0^{2n} T_0^{2m}/gP_0^Q$$
$$Q = 2\,[n + m\,(y-1)]/y$$

The following derivation of a value[7] for $V_2 - V_1$ is based on the assumption that the expansion of the gas

in passing through the flame-front is equal to that which would result from the liberation of the same amount of heat during combustion at a constant pressure equal to the pressure at the rear of the flame-front.

For constant pressure burning

$$h = C_p(T_2 - T_1)$$
$$= (C_p/R)\,(P)\,(V_2 - V_1)$$

where

$C = hR/C_p$

C_p = the specific heat at constant pressure

h = the effective heat value per pound of gas

$R = 778\,(C_p - C_v)$

hence

$$V_2 - V_1 = hR/C_pP$$
$$= C/P$$

and, in this case,

$$V_2 - V_1 = C/P_2 \qquad (10)$$

By substituting the derived equivalents for (W^2/g) and $(V_2 - V_1)$, already stated, in the basic equation $P_1 - P_2 = (W^2/g)\ (V_2 - V_1)$, we obtain

$$W^2/g = LP_1^Q \qquad (3)$$
$$V_2 - V_1 = C/P_2 \text{ (Approximate)}$$

then

$$P_1 - P_2 = W^2/g\,(V_2 - V_1)$$
$$= LP_1^QC/P_2$$
$$= MP_1^QC/P_2 \qquad (5)$$

where

$$M = LC$$

APPENDIX 2

Determination of Critical Pressure of Detonation

If $P_1 - P_2$ be plotted against P_2 in equations (4) and (5) it is found that P_2 reaches a maximum value corresponding to the critical pressure of detonation. Therefore, if, in these equations, $P_1 - P_2$ be differentiated with respect to P_2 an expression may be derived defining this critical point.

$$P_1 - P_2 = (LP_1^Q \times C)/P_2$$
$$= MP_1^Q/P_2$$

where

$M = L \times c$

Let

$$P_1 - P_2 = z$$
$$P_2 = x$$

then

$$z = [M(x+z)^Q]/x$$

or

$$x = [M(x+z)^Q]/z$$

Differentiating

$$dx = \frac{MzQ(x+z)^{Q-1}\,dz - M\,(x+z)^Q dz}{z^2} + MQ(x+z)^{Q-1}dx$$

$$dx\left[1 - \frac{M}{z}\,Q(x+z)^{Q-1}\right]$$
$$= dz\left[\frac{M}{z}\,Q(x+z)^{Q-1} - \frac{M}{z^2}\,(x+z)^Q\right]$$

$$\frac{dx}{dz} = \frac{\frac{M}{z}\,Q(x+z)^{Q-1} - \frac{M}{z^2}\,(x+z)^Q}{1 - \frac{M}{z}\,Q(x+z)^{Q-1}}$$

x is a maximum when $\frac{dx}{dz} = 0$

Let

$$\frac{M}{z}(x+z)^{Q-1}\left[Q - \frac{x+z}{z}\right] = 0$$

then

$$\frac{M}{z}\,(x+z)^{Q-1} = 0$$
(indeterminate)

or

$$Q - (x+z)/z = 0$$
$$z\,(Q-1) = x$$
$$z = x/(Q-1)$$

Substituting in the original equation we have

$$z = [M(x+z)Q]/x$$

$$\frac{x}{Q-1} = \frac{M\left(x + \frac{x}{Q-1}\right)^Q}{x}$$

$$x = \sqrt[Q-2]{\frac{(Q-1)^{Q-1}}{MQ^Q}}$$

or

$$P_2 = \sqrt[Q-2]{\frac{(Q-1)^{Q-1}}{MQ^Q}}$$

where

C_p = the specific heat at constant pressure

C_v = the specific heat at a constant volume

D_o = the density at ignition

$g = 32.2$

h = the effective heat-value per pound of mixture or the product of the pounds of fuel per pound of mixture times the heat value per pound of fuel times the efficiency of combustion times

$$\left[\frac{1 - (Cl \times \frac{P_a}{P_o}}{CV}\right]$$

K = the constant of reaction velocity

$$M = LC = \left(\frac{K^2D_o^{2n}T_o^{2m}}{gP_o^Q}\right) \times \frac{hR}{C_p}$$

m = an experimentally determined exponent

n = an experimentally determined exponent

P_o = the pressure at ignition

P_2 = the critical pressure of detonation

$Q = \frac{2}{z}\ [n + m\,(z-1)]$

$R = 778\ (C_p - C_v)$

T_o = the absolute temperature at ignition

Since the adiabatic compression of the unburnt gas ahead of the flame-front is really an extrapolation of the compression performed by the piston, D_o, P_o and T_o in the above formula can be taken as the condition of the mixture at the closing of the inlet-valve as well as that at the point of ignition. In this form the expression can be used more readily in calculations.

The values of m, n and Q, that were found to check the observed data, are $m = 3.22$, $n = 0.9$ and $Q = 3$. Equation (6) thus becomes

$$P_2 = 0.148/M \qquad (7)$$

Research Topics and Suggestions

THE Research Department plans to present under this heading each month a topic that is pertinent to the general field of automotive research, and is either of special interest to some group of the Society membership or related to some particularly urgent problem of the industry. Since the object of the department is to act as a clearing-house for research information, we shall be pleased to receive the comments of members regarding the topics so presented, and their suggestions as to what might be of interest in this connection.

TESTS—RELIABLE AND OTHERWISE

THE correspondence, published papers and advertising matter that come to the attention of the Research Department frequently quote laboratory tests and expressions of opinion on technical subjects that are by no means as reliable as they should be. Such instances are especially frequent in connection with reports of newly developed devices and equipment. We believe that these instances are the result of failure of some engineers to appreciate the importance of some of the factors that are essential to the securing of reliable test-results and to the deduction of reliable conclusions from them.

It would take a textbook to cover even briefly all the factors involved in the testing of appliances alone. A few of these factors, however, seem to be peculiarly subject to neglect. Nearly all of the special appliances, accessories or materials, tests of which are requested from time to time for the information of the producers, or for advertising purposes, are in a competitive position. Only rarely does an entirely new product appear, but what follows applies with almost equal force in this case also.

The usefulness or probable success of any particular product is always a matter of relative values. For instance, to know whether a new type of wheel is worth producing, we must know, not whether it is a *good* wheel, but whether it is better, or cheaper or possesses other advantages over the other types of wheel in use. Even if the product is in a new or non-competitive field, its value still depends upon its relation to other products. Failure to recognize this general fact is one of the common causes of unreliable test-results.

It is all too common an occurrence to find in print or in letters of commendation the results of tests of various appliances, made by engineers or in laboratories whose reputations carry great weight, but which tests were obviously made without adequate knowledge of other similar appliances. To take a concrete but hypothetical illustration, John Doe in charge of the Excelsior Laboratory reports as follows on the test of a vacuum cleaner:

> This cleaner weighs 41 lb.; it contains an alternating current motor which runs at 8700 r.p.m. and requires 200 watts on a 110-volt 60-cycle circuit. It produces a suction of 12 in. of water when the cleaner nozzle is closed, and moves 100 cu. ft. of air per min. when the nozzle is open. It was tested on a 6 x 9-ft. Persian rug into which had been rubbed 6 oz. of flour. The amount of flour caught after 5-min. operation by an inexperienced operator was 5½ oz.
>
> We conclude from these tests that this vacuum cleaner is a thoroughly reliable and satisfactory machine.

This report, backed by the name of John Doe of the Excelsior Laboratory, might have great weight with the public and be of commercial value to the salesmen of the device but, as there are a good many varieties of vacuum cleaner on the market that differ from this one in respect to every single item reported, this test fails to give the slightest information to the hypothetical vacuum-cleaner engineer as to the real merit of this particular machine, unless he himself knows the corresponding figures for at least a large part of the other machines on the market. John Doe would never append his name or that of the Excelsior Research Laboratory to such a test if he realized its essential unreliability as a real indication of merit.

Another less obvious but perhaps more important fault in many test-results is failure to take account of essential principles. When an inventor presents a perpetual-motion machine, and calls it such, he gets no hearing, but there are scores of perpetual-motion machines presented with such confusion of detail that occasionally some engineer is tricked into making a report on some of them without realizing that it violates the principle of the conservation of energy.

But there are other principles as important and fundamental as the latter, the application of which would prevent many mistakes. Most of these are, or should be, familiar to all experimentalists, but the applications are not always obvious. For instance, Newton's law, stated briefly, that "action and reaction are equal and opposite," applied to the simple case of a shaft implies that the torque on the driven end cannot exceed that on the driving end. And this is true even if the shaft is cut in two and any sort of a mechanism interposed between the ends, so long as this mechanism has no reactions on anything but the shaft itself. Yet we find every little while a new discussion or a test of some sort of transmission that obviously violates this principle and therefore cannot possibly do what is claimed for it.

One of the most conspicuous faults of test results is, too many variables changed at the same time. In its worst phases, this practice represents actual fraud. For instance, the enthusiastic purveyor of some gasoline-improver, or of a device for improving carburetion, makes a test for mileage with a second-hand car *as is*, or even guesses at the probable mileage of such a car, then he puts in his "dope" or installs his device, readjusts the carbureter, and perhaps scrapes carbon, grinds valves and does a few other things of the same kind, after which he compares the new mileage with the old. No reputable engineer would do quite this, yet it is all too common to find tests run by University laboratories or by engineers who have not seen the importance of controlling and checking test conditions so that results are really comparable.

What should have been done in the test just mentioned is this: the car should have been reconditioned first; then several tests should have been run alternately with and without the new dope or device, taking care that weather, road and driving conditions were substantially constant. The methods of using blank or check tests are too familiar and too numerous to mention here, but the frequency with which they are neglected constitutes a severe criticism of the common test-procedure.

There has been much justified criticism of tests, more particularly of those run in the laboratory, to the effect that they do not represent actual service conditions. It is usually possible with sufficient skill, experience and laboratory equipment to run almost any test in the laboratory that can be run in service and to get results that check service conditions. It is also possible, usually, to get results under service conditions that have most of the reliability and accuracy of laboratory results, provided enough skill and equipment are at hand. Sometimes one method and sometimes the other is easier, but to be sure that the results are at the same time accurate, reliable and representative of actual service is one of the most difficult phases of test procedure.

When a University or private laboratory, or a consulting engineer, makes a report on any test whatever, such a report, of course, carries weight in proportion to the reputation of the man or institution whose name is attached to it. In the

case of laboratories, such reports, although made and signed by an individual, still carry weight, depending on the laboratory's reputation.

The observations that led to this discussion have convinced us that no laboratory should allow test reports to go out, in the name of the laboratory or of any individual, without a careful check as to their reliability. Both the laboratory and the individual engineer who reports the results of tests, either by publication or in private, are under an obligation to the engineering fraternity, to the public and to the parties for whom tests were made to see that unreliable and misleading results are avoided so far as is possible.

A SURVEY OF CURRENT LITERATURE

THE RESEARCH staff of the Society regularly reviews more than 80 publications, American and foreign, bearing on the automotive industry. The articles summarized and indexed below were selected because of their probable interest to readers who do not have access to more than a few publications in the automotive field.

The Research Department invites inquiries from members who may be interested in any of the topics discussed here. Copies of all articles, clippings and pamphlets mentioned are kept on file for the information of our members.

Gasoline Specifications Revised

The latest revisions of the Federal Specifications for Motor Gasoline and other petroleum products appear in Technical Paper No. 323 of the Bureau of Mines, published by the Government Printing Office, City of Washington; price, 10 cents.

The outstanding change is in automobile gasoline, for which the latest specifications read as follows:

PROPERTIES AND TESTS

Color—Method 10.1. The color shall not be darker than No. 16 Saybolt

Corrosion Test—Method 530.21. A clean copper strip shall not be discolored when submerged in the gasoline for 3 hr. at 122 deg. fahr.

Distillation Range—Method 100.11. When the first drop has been recovered in the graduated receiver, the thermometer shall not read more than 55 deg. cent. (131 deg. fahr.) . . . (The former specification was 60 deg. cent. or 140 deg. fahr.). When 20 per cent has been recovered in the receiver, the thermometer shall not read more than 105 deg. cent. (221 deg. fahr.). When 50 per cent has been recovered in the receiver, the thermometer shall not read more than 140 deg. cent. (284 deg. fahr). When 90 per cent has been recovered in the receiver, the thermometer shall not read more than 200 deg. cent. (392 deg. fahr.). . . . (Former specification was 190 deg. cent. or 374 deg. fahr.). The end-point shall not be higher than 225 deg. cent. (437 deg. fahr.). At least 95 per cent shall be recovered as distillate in the receiver from the distillation.

High-Speed Oil-Engines

A paper by J. L. Chaloner, published in preprint form by the Institution of Automobile Engineers under the above title, in February, 1923, emphasizes the technical characteristics of the high-speed oil-engine when applied to the automobile. The paper is reviewed in *Engineering* (London) as follows:

> The author classifies the different types of engine in accordance with their fundamental principles of operation, and finds it possible to do so without introducing names of inventors or firms into the nomenclature. The main part of the paper is devoted to consideration of the design of complete engines or of mechanical details, thus presenting in a handy form a large collection of matter of great interest to the designer. Tables giving the leading particulars of numerous engines, together with data as to their performances, and, in many cases, their respective heat-balances, add to the value of the paper. Mr. Chaloner concludes by appealing for a simple system of nomenclature based on the technical characteristics of the various classes of oil engine, so that the name would define the type of engine and avoid the confusion at present existing. He considers that the limiting dimensions of the present type of engine are well known, being controlled by mechanical and metallurgical properties of the materials employed. No system of fuel utilization which yields a maximum possible return of only 50 per cent will remain satisfactory to engineers, and Mr. Chaloner appears to envisage the future discovery of some new and more efficient cycle for internal combustion.
>
> However this may be, the modern internal-combustion engines are at present the most efficient machines known for converting fuel energy into work, and the author's review of those using oil as fuel is a most useful contribution to the literature of the subject.

The Technique of Calculation

A review of James Watt's paper, Automobile Calculations, appeared in the December, 1922, issue of THE JOURNAL. In this paper the author suggested practical methods by which certain characteristic problems could be tackled. His primary object in writing the paper was to afford assistance to those personally responsible for carrying out the calculations. A supplementary paper, under the above title, that has been prepared chiefly for the benefit of those responsible for the organization and supervision of such work, appears in the *Automobile Engineer* for February, 1923, p. 59.

Some Interesting Gaging Appliances

A number of novel and effective machines for Gear Inspection and Piston-Ring Testing are described and illustrated in *Engineering Production* for Jan. 15, 1923. One of them is the Saurer piston-ring testing apparatus for verifying the pressure exerted by the rings when compressed. Another appliance, designed for testing spur gears for the pitch and the distance between the centers of the wheels, and an apparatus for checking accurately the play of the teeth and the concentricity of the gear wheels, are likely to be of interest to many of our readers.

Aeronautical Nomenclature

To insure greater uniformity and accuracy in official documents and in trade and technical publications dealing with aeronautical subjects, a special conference authorized by the National Advisory Committee for Aeronautics prepared Report No. 157, which was issued under the above title. The report is divided into three sections: Alphabetical Nomenclature, Nomenclature by Divisions and Aeronautical Symbols. The subject is covered thoroughly in this timely publication.

Notes on Aerodynamic Forces on Airship Hulls

The failure of the airship ZR 1 a disaster that is still fresh in most minds, was probably due to a lack of knowledge of this particular problem, which has been worked out mathematically by the author, L. B. Tuckerman, engineer physicist of the Bureau of Standards. The article appears as No. 129 of the Technical Notes of the National Advisory Committee for Aeronautics.

High-Speed Engine Indicators

The problems of the engine indicator are covered very thoroughly in four papers read before the British Institution of Mechanical Engineers, Jan. 19, 1923, and published in *Engineering* for Jan. 26, 1923. These papers and the dis-

cussion that followed them are reviewed critically in *Engineering* for Feb. 16, 1923, attention being drawn to the Midgley indicator that was not mentioned at the meeting, but which possesses one or two special features that meet points of criticism raised by various speakers.

Multi-Wheel and Track Motor-Vehicles

T. G. Tulloch, in a paper issued by the Institution of Automobile Engineers as preprint, in March, 1923, discusses the following factors in the economics of land transportation other than by railroad: reduction in the cost and the maintenance of roads; reduction in the taxation of the vehicles; increases in the carrying capacity of the roads; increase in the carrying capacity of the vehicles; increase in the speeds; reduction in the running costs and the maintenance of the vehicles; influence on future wars.

Torsion of Crankshafts

S. Timoshenko in *Mechanical Engineering* for February, 1923, considers the case of a crankshaft with a single throw and establishes the mathematical relations for such a case. He investigates three conditions for such a crankshaft: (*a*) no constraint, corresponding to ample clearance in the bearings; (*b*) complete constraint, corresponding to no clearance in the bearings; (*c*) partial constraint, corresponding to ample clearance in the halves of the bearings nearest the web and no clearance in the other halves.

Effect of Repetition Stresses on Materials

The efforts made by research workers during the past few years to determine the fatigue range of materials, and to estimate the conditions that determine failure under repeated stresses illustrate the growing importance of these problems to engineers. In a paper read before the Institution of Civil Engineers, at Birmingham, Prof. F. C. Lea discussed these questions in the light of recent experience. The work of H. F. Moore and J. B. Kommers on the Fatigue of Metals, published as a University of Illinois Bulletin, No. 124, in 1921, covers some of the points discussed in Professor Lea's paper. The results of repeated stress tests of various materials at various temperatures are given in tabular form in this interesting paper, which appeared in *Engineering*, Feb. 16, 1923, p. 217, and Feb. 23, 1923, p. 254.

Gearboxes for Motorcycles

A paper by I. Cohen that was issued by the Institution of Automobile Engineers as a preprint in March, 1923, contains a critical study of the design and construction of motorcycle gearboxes, gears and clutches.

A Comparative Test

The *Autocar* in its issue of Feb. 16, 1923, pp. 252-255, presents the results of a comparative test of a Peugeot 15-hp. four-stroke four-cylinder gasoline engine and a Peugeot-Tartrais 15-hp. two-stroke two-cylinder heavy-oil engine.

Non-Skid Tire-Tread Design

H. W. Perry in *India Rubber World* for March 1, 1923, discusses the principal requisites of a superior design which are stated as resistance to side-slip and spinning; resistance to wear; freedom from suction and noisiness; attractive appearance and distinctiveness.

Burnishing the Teeth of Gears

In an article in the *American Machinist* for March 1, 1923, Ellsworth Sheldon describes a process that corrects minor errors of contour, smooths and densifies tooth surface, forestalls effects of distortion in hammering; analogous to cold-hammering.

The Oscilloscope

Engineering Production (London), Nov. 16, 1922, contains notes on a new and useful optical mechanical device with many applications to automotive engineering work.

TEST OF AIR-CLEANERS FOR TRACTOR ENGINES

A REPORT on the performance of 26 air-cleaners for tractor engines was presented before the American Society of Agricultural Engineers by A. H. Hoffman, who made the tests and developed an accurate laboratory method for determining dust-separating efficiency. This method, which makes possible a reliable comparison of the cleaners, requires a standard air-floated dust, which can be kept in an unchanged condition indefinitely. This dust is fed to all cleaners in the same manner and at the same rates by an ingenious dust-feeding mechanism. A known weight of the dust is mixed with the air entering the cleaner to be tested; the dust not retained by the cleaner is removed by an "absolute cleaner" that is designed so that the dust collected by it can be weighed accurately or compared photographically.

The efficiencies thus determined for nine oil-type cleaners range from 94.7 to 99.9 per cent; for the nine water-type cleaners, from 83.6 to 97.3 per cent; and for eight dry-type cleaners, from 37.6 to 99.5 per cent. Each cleaner was subjected to at least three test-runs, during which it was connected with the 1½-in. Kingston model-L carbureter of a Weidely Model MAU engine of 22.5 rated hp. The normal engine-speed was kept at 1200 r.p.m., and the dust was fed at the rate of 50 grams in 30 min. The three test-runs were made respectively under normal load of 20.4 hp., under light load of 12.6 hp., and under service conditions of variable load, variable speed, quick pick-up with wide-open throttle, idling and backfiring. The service test showed lower efficiency for a number of cleaners.

The dust-separating efficiency, although the most important feature, is not alone sufficient to determine the relative merits of cleaners. Thus, the vacuum at the carbureter intake due to the attached cleaner may affect the power of the engine, especially when the cleaner becomes filled with dust and dirt. A series of power determination with and without cleaners attached seemed to indicate that this effect is slight so long as the cleaner has collected but little dust. As the cleaner fills-up, however, the vacuum increases very fast with some cleaners, but not with others. In this respect the water-type cleaners showed the best performance, for in all nine of the water-type cleaners under the test the vacuum was independent of the amount of dust collected. Of the nine oil-type cleaners, four showed a vacuum proportional to the amount of dust collected; the same was true of one of the eight dry-type cleaners. This "fill-up" test was designed to exhibit the ability of the cleaner to work under gross neglect and abuse. In a general way the results give some idea of what might be expected of the cleaner when given no attention until it is filled up with dirt. When a cleaner under this test book 5 lb. or more of the dust without an appreciable rise in the vacuum and without loss of dust-separating efficiency, it was considered that the particular cleaner's ability to stand neglect has been established satisfactorily.

A number of the cleaners had intakes that were not screened properly and their construction was such that the presence of vegetable refuse might affect the vacuum. These cleaners were put to a special test, in which air-dried wheat chaff was sifted into the airstream and vacuum readings taken. Finally, the water-type cleaners were intercompared for performance when the water-level was low. Both of these special tests revealed cleaner characteristics that were not indicated by the dust-separating efficiencies.

Mr. Hoffman's tests constitute the most comprehensive study of air-cleaners that has ever been made, and the details of the tests, now on file in the office of the Agricultural Engineering Division, University Farm, Davis, California, may be studied profitably by everyone interested in tractors. The results of the tests will be published in a forthcoming volume of the *Transactions of the American Society of Agricultural Engineers.*

Vol. XII April, 1923 No. 4

A Critical Study of Modern Automotive-Vehicle Steering-Systems

By HERBERT CHASE[1]

ANNUAL MEETING PAPER *Illustrated with* DRAWINGS

STATING that automotive literature presents surprisingly little helpful information concerning the faults of the steering-systems used on automotive vehicles and that, in spite of the fact that so many of the faults are self-evident, they frequently are overlooked in actual practice, the author includes with the presentation of his own investigations summaries of the views expressed by numerous well qualified automotive engineers and discusses these steering-gear faults in some detail.

Beginning with the subject of safety, consideration is given successively to the causes of hard steering, the angular position of knuckle-pivots, knuckle-pivot location, the foregather or toe-in of wheels, castering or trailing effect, wheel-wabble, drag-link location, irreversibility, steering-gear type comparisons, tie-rods and tie-rod arms. Numerous drawings illustrative of present-day practice are presented and commented upon, reference being made also to other articles, printed previously, that are pertinent.

STEERING-SYSTEMS employed on many modern passenger-cars and trucks are known to have certain faults, but the literature of the automotive industry contains surprisingly little helpful information regarding either these faults or the factors that should control the design of the system as a whole. Neither the TRANSACTIONS of the Society nor the *Proceedings* of the British Institution of Automobile Engineers contain any papers dealing with the subject except by incidental or casual reference. It has, therefore, seemed highly desirable to collect here certain data pertaining to various parts of the system, and to discuss the arguments advanced for the several types of construction employed and their layout or arrangement in reference to other parts. The effect upon the operation and performance of the vehicle will be considered also.

No claim for originality in the material presented is made. Many of the facts given can be said to be virtually self-evident, yet it is surprising how frequently they are overlooked in actual practice. I have been assisted greatly in preparing the paper by several members of the Society. In fact, the views expressed are formulated largely by summarizing the opinions of a number of well-qualified engineers, including several of those most prominent in the automotive industry.

Steering-systems as a whole have been changed but little for many years. The conventional layout has operated with reasonable satisfaction in most cases; so, it has been given relatively little attention as compared to other parts of the chassis that demanded intensive development. As a result, the steering-system has lagged behind in the general development of motor vehicles. It is hoped that the data assembled in this paper will encourage further study of the subject and result ultimately in a decided improvement in steering systems.

SAFETY

It may seem almost superfluous to discuss the matter of safety as affecting steering-system design, but the fact is that far too little attention has been given to this factor, which should be the primary consideration in the design of most parts of every self-propelled vehicle. Important details, such as means for locking the yokes properly to the tie-rod, are overlooked too frequently. Lost motion that results at this and other points frequently makes the vehicle unsafe. I know of instances where it has been necessary to braze the yokes and the tie-rod together before the joint would remain tight. Serious accidents are said to have resulted from failure to give attention to items of this character. One manufacturer of steering-gear parts states that some automotive manufacturers refuse to accept parts in which the limits are held sufficiently close to insure good fits, simply because such parts cannot be assembled so rapidly as others that are given more clearance. A policy of this character is certainly not in the interest of safety and, therefore, cannot be criticised too severely. Other points in the steering-system are open to similar criticism. When one stops to realize the importance of safe steering-systems, especially under modern conditions of traffic congestion, it is evident at once that no pains should be spared to make the steering-system safe. What user would not gladly pay a few dollars more for a car with a safe system than for one having a steering-system open to criticism in this respect?

I shall refer only to the conventional steering-system in which the two front wheels are mounted on spindles attached to the axle by pivoted knuckles so that their angular position is controlled by a steering-gear connected to the knuckles by a drag-link and tie-rod.

It is desirable, manifestly, to layout such a system in a manner that will permit all four wheels of the vehicle to turn about a common center without any sliding action when the vehicle turns a corner. To meet this condition, it is necessary that the horizontal projection of the axes of all four wheels meet at a common point in all positions of the wheels. To fulfill it exactly would require that the locus of the point of intersection be a straight line coinciding with the axis of the rear axle, a condition that cannot be met precisely with the conventional linkage. It is fulfilled approximately when the arrangement is such that the horizontal projection of lines drawn through the centers of the knuckle-pivot and the eyes or balls on the arms to which the tie-rod is attached meet in the central vertical plane of the car at or slightly forward of the center of the rear axle. Articles[2] by J. L. Napier, discussing the geometry of this layout, have appeared in the technical press. Unless this rule is followed, excessive tire-wear and hard steering are apt to result.

[1] M.S.A.E.—Engineering editor, *Automotive Industries*, New York City.

[2] See *Automobile Engineer*, July, 1910, p. 35; see also the Gasoline Automobile, by P. M. Heldt, vol. 2.

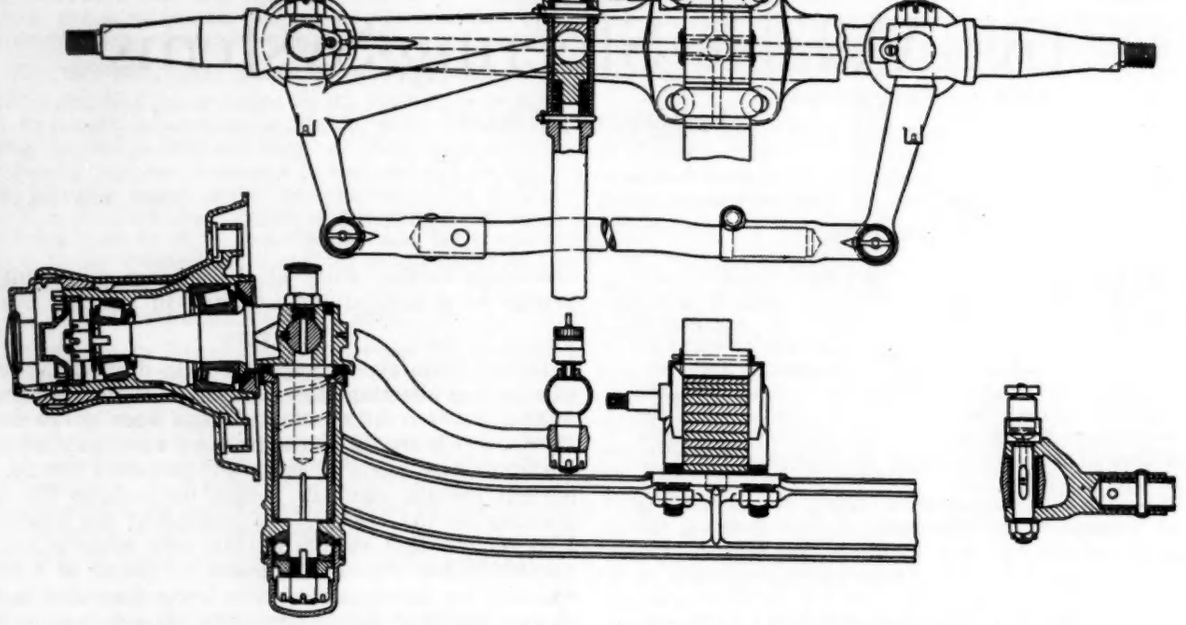


FIG. 1—THE KNUCKLE-PIVOT DESIGN OF STEERING-MECHANISM USED ON THE MARMON CAR

CAUSES OF HARD STEERING

Among the common faults of the steering-system is the excessive effort required in its normal operation. The primary causes of hard steering are friction and faulty design of the system, the latter frequently resulting in the former. Friction can, of course, occur at many points and for a great variety of reasons, some of which will be enumerated.

(1) Inaccurate machine work at joints and bearing surfaces
(2) Careless assembly, often resulting in lack of alignment
(3) Insufficient lubrication
(4) Failure to exclude dirt and moisture
(5) Excessive bearing pressures
(6) Under-inflation, condition, type and construction of tires
(7) Faulty design

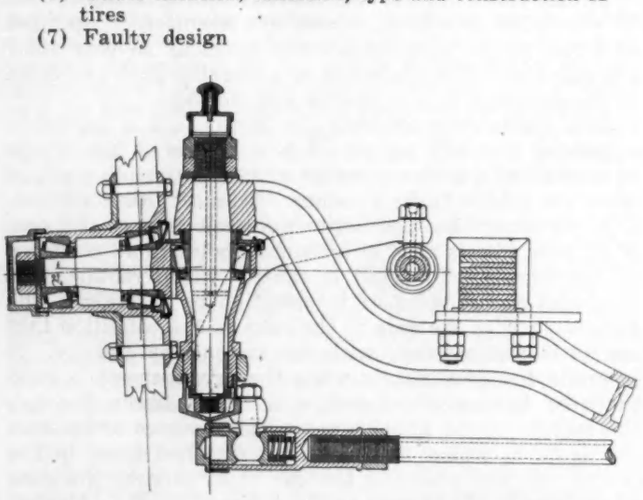


FIG. 2—THE LATEST CRANE DESIGN OF STEERING-KNUCKLE WHICH INCORPORATTES A VERTICAL PIVOT WITH A ROLLER THRUST BEARING AND A WELL THAT PERMITS ALL BEARINGS TO BE KEPT IN A BATH OF OIL

Under (1), nearly all parts of the steering-gear can be cited; the balls and the sockets in the drag-link, the king-pins and their bushings and the tie-rod joints. It is not contended that these units are always subject to faulty machine work, but instances in which they have given trouble on this account are fairly common.

Numerous examples of careless assembly (2) occur.

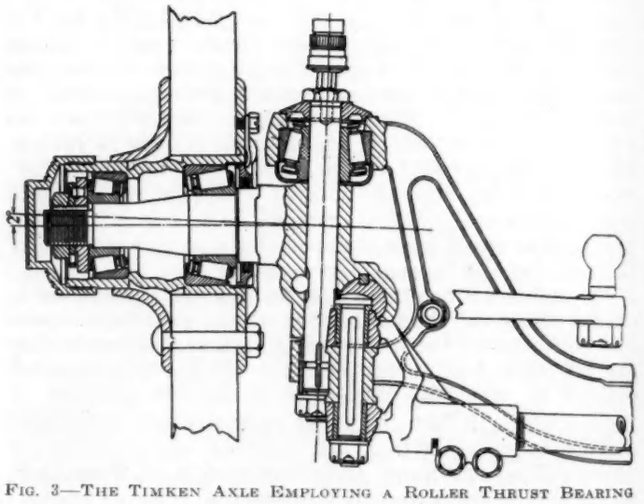


FIG. 3—THE TIMKEN AXLE EMPLOYING A ROLLER THRUST BEARING

A common one is the fitting of the steering-column in the support at the dash. This is sometimes sprung into place after the lower end of the gear is bolted in position, with results that obviously are poor. Another is the forced fitting of the king-pins and a third is the use of excessive spring pressures on drag-link and tie-rod bolts.

Insufficient lubrication (3) is so common a fault, especially at the king-pins and at drag-link and tie-rod joints, that these parts wear rapidly and often rust. The steering-gear usually is filled originally with heavy oil that fulfills its purpose well so long as it remains in

place, and the same can be said of the knuckle-pins on a few cars. Excellent examples of good construction in this respect are the Marmon and Crane designs shown in Figs. 1 and 2. In both of these the bearing surfaces are arranged so as to be submerged in a well of oil. The only place for the oil to escape is at the top of the wells, where felt washers are fitted. In the Crane design the aim is to maintain a small head of oil above the bearings. The use of a hair filling in the oil reservoir helps by its capillary action to prevent loss of oil at the top of the well. The arrangement is such that no gun is required for renewing the oil supply. While this Crane design is still in the experimental stage, it appears to have much to commend it.

Several of the designs show good examples of the use of ball thrust-bearings for supporting the weight of the car; while the Crane design, Fig. 2, and the Timken design, Fig. 3, the latter being used on Dorris and other cars, illustrate the use of roller-type thrust-bearings. Such bearings, if well protected from dirt and water, undoubtedly have much to commend them, and should help greatly in minimizing friction. Another and rather

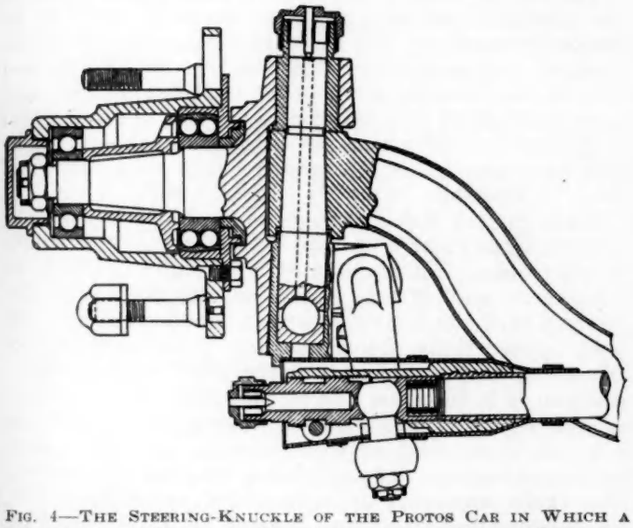


FIG. 4—THE STEERING-KNUCKLE OF THE PROTOS CAR IN WHICH A SINGLE LARGE-DIAMETER BALL SERVES AS THE THRUST BEARING

novel form of thrust bearing consisting of a single large ball is used in the knuckle of the German Protos car, as shown in Fig. 4. This arrangement appears to have the advantage of simplicity and moderate cost.

Anti-friction bearings, of both the ball and the roller types, are frequently used in the steering-gear, especially to take thrust but also for radial loads. The Marmon and Vauxhall gears, shown in Figs. 5 and 6, furnish examples in this connection. Such bearings certainly help to minimize friction, but they have certain disadvantages in respect to higher first-cost. In some cases they are subject to a hammering action, especially when solid tires are employed, which is destructive and may cause corrugating of the bearing surface, particularly if the loads are heavy.

Lubrication of drag-link and tie-rod joints is usually a decidedly hit-and-miss factor, and is seldom given sufficient attention when it depends upon a hand operation. An excellent design is one in which the ball joints are made as nearly oil-tight as possible, and the tube filled with oil which keeps the ball surfaces well lubricated. A design of this character is said not to require attention oftener than once in 6 months. Other points that frequently cause excessive friction are the bearings in the

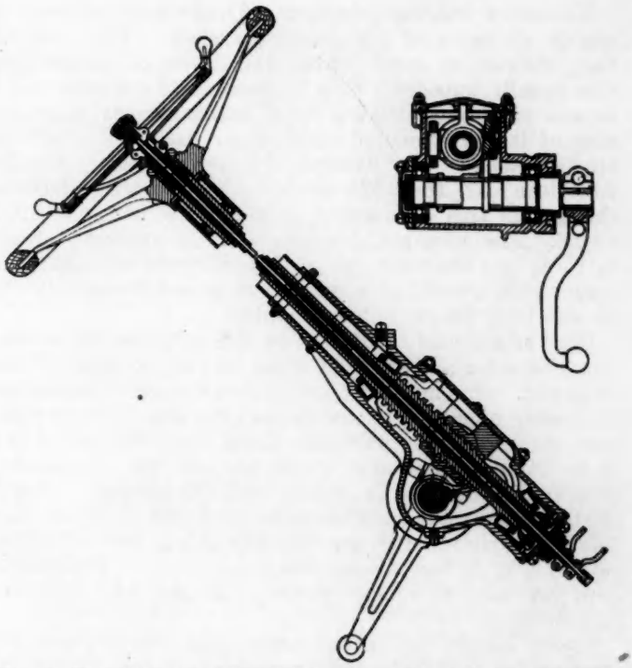


FIG. 5—THE MARMON STEERING GEAR IN WHICH ANTI-FRICTION BEARINGS ARE USED IN THE STEERING COLUMN AND ON THE STEERING-LEVER SHAFTS

steering-column. They are apt to be overlooked when lubrication of other parts is given attention.

Failure to exclude dirt and moisture (4), especially at drag-link, tie-rod and knuckle-joints, naturally results in excessive friction and rapid wear. Provision for adequate lubrication at all times, by means that tend to force dirt out of rather than into bearings, is a kind of antidote, partly because a good lubricant properly applied tends to prevent rust and foreign matter from accumulating on the bearing surfaces, and partly because the constructions that keep the lubricant in place frequently are fully as effective in excluding dirt. A ball-and-socket joint properly enclosed has certain advantages over the yoke-and-pin type in respect to the facility with which lubricant can be kept on the surfaces, as well as in freedom from rattle or binding, one of which defects is almost certain to occur with the conventional yoke and pin.

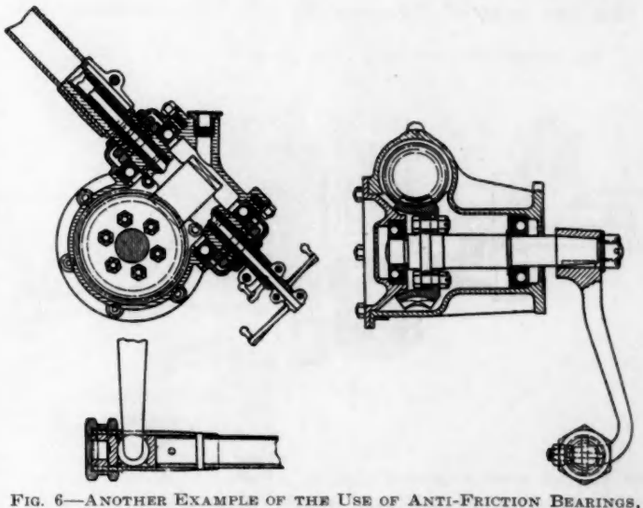


FIG. 6—ANOTHER EXAMPLE OF THE USE OF ANTI-FRICTION BEARINGS, THE VUXHALL STEERING GEAR

Excessive bearing pressures (5) are very common in nearly all parts of the steering-system. They are, in fact, difficult to avoid within the limits of weight and size usually imposed. It is impossible to consider many details of specific designs here, but it can be said that pins of larger diameter with longer bushings often are applied easily. For example, in the case of one light American car, the 1923 model will have the following changes in this connection, as compared with the 1922 model. The king-pin diameter will be increased from ⅝ to ¾ in.; the bushings in the axle yoke will be ¼ in. longer; the tie-rod pins will be increased from ½ to ⅝ in. and their length will be doubled.

Ease of steering is affected by tire inflation (6) condition, character and width of tread, and by the type of tire employed. One authority states that the static resistance to turning offered by a tire varies inversely as the square root of the inflation-pressure. Cord tires, because of the lower inflation-pressures employed, and the consequent greater area of tread in contact with the ground, are said to steer harder than the same nominal size of fabric tire when properly inflated; but whether this is true when the vehicle is in motion is open to some question. Pneumatic tires are said to render steering harder than solid or cushion tires.

Faulty design (7) often contributes heavily to hard steering, as will be noted from some of the foregoing items. Too small a steering-gear with insufficient leverage is one frequent fault but, of course, it is poor economy to employ a large reduction giving a great leverage simply to overcome friction which is higher than necessary, though this is sometimes done. A much more logical procedure is to minimize friction and then apply a gear with sufficient reduction to accomplish the purpose for which it is intended without requiring undue exertion upon the part of the operator.

Incorrect location of the steering-arms and distortion of various parts of the steering-system either under the load of the vehicle or under that imposed by the steering operation are other factors that frequently contribute to hard steering. Distortion often results in binding which, in turn, causes excessive friction. In some cases the pressures imposed are so heavy as to cause the oil-film to be squeezed out and the parts to seize or score. This results in a rough surface that offers increased friction and causes rapid wear.

When a yoke-and-pin construction is used on the tie-rod it is necessary, to prevent binding, to make sure that the axes of the pins are precisely parallel to the axes of the knuckle-pins and to each other. Careless assembly, or the load imposed upon the axle after assembly, often results in a lack of parallelism of the parts in question, with the inevitable result that excessive friction occurs. This is another reason for favoring the use of a ball and socket on the ends of the tie-rod arms.

[3] See *Automotive Industries*, Nov. 30, 1922, p. 1068.

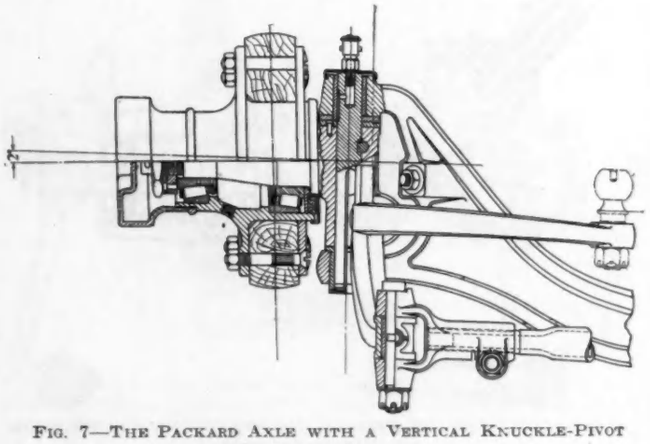


FIG. 7—THE PACKARD AXLE WITH A VERTICAL KNUCKLE-PIVOT AND PLAIN BUSHINGS

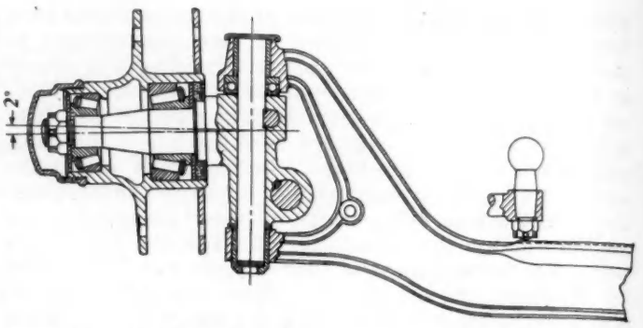


FIG. 8—THE COLUMBIA AXLE-END, ANOTHER EXAMPLE OF THE VERTICAL KNUCKLE-PIVOT CONSTRUCTION

The proper finish of bearing surfaces and a provision for adequate clearance at these surfaces seem to be obviously necessary, but they are frequently overlooked. Another item sometimes forgotten is that an inclined axis of the steering-pivot, other than one which gives true center-point steering, raises or tilts the front end of the car when the wheels are deflected from the straight-ahead position. This, of course, requires some additional effort in steering.

Other factors that contribute to hard steering are the weight on the front wheels of the vehicle, and the length of the moment-arm represented by the distance between the central point of tire contact and the point at which the axis of the knuckle-pivot, when produced, strikes the road. Other things being equal, it is desirable, in the interest of easy steering, to proportion the vehicle as a whole so as to make the load on the front wheels as small as possible. It is desirable also to keep the moment-arm referred to as short between knuckle and wheel parts as proper clearance and manufacturing conditions permit. This again may seem to be an almost self-evident fact, but it is one that sometimes is given too little consideration. One manufacturer recently showed me how this moment-arm easily could have been decreased almost 1 in., and without any increase in cost, in the case of the axle he was purchasing from a parts maker, if the designer had given proper attention to this factor in making the original layout. Additional factors that create unnecessary friction are introduced if the amount of foregather of the wheels is excessive or if the layout of the drag-link, knuckle-arms and other parts of the steering-system is not correct. The geometry of the system has been treated with reasonable thoroughness in several textbooks and in some engineering papers to which reference is made elsewhere; but it is given too little consideration, especially in the case of some cars that are assembled from units, the inter-relation of which is not given sufficient study.

In a recent article by E. M. Caskey, a steering-gear manufacturer, entitled Hard Steering as a Result of Inaccurate Manufacture and Assembly,[3] it is stated that it has proved practically impossible to build a car in such a way as to have free-steering qualities and still have good road-holding qualities at moderately high speeds. We have yet to find any engineer who agrees with this view. It is true that, in some cases, a free-steering car will bring to light faults in the steering-

system that, in a harder steering car of similar general design, would not be evident. This is due to the fact that certain inherent faults, especially the tendency to wheel-wabble, are not infrequently damped-out by friction which, if it is decreased, tends to make these inherent faults apparent; but it does not follow necessarily that easy steering and good road-holding qualities are incompatible. In fact, there is good reason to believe that, when the steering-system is designed properly and therefore is reasonably free-acting, the road-holding characteristics of the vehicle will not be impaired.

Angular Position of Knuckle-Pivots

Many characteristics of the steering-system, especially in respect to performance, are dependent upon the angular position of the knuckle-pivots. Knuckle-pivot axes as seen in front elevation usually are made vertical in the case of American cars and trucks, and the same is true of many foreign-built vehicles. Examples of the vertical pivot are the Packard axle, Fig. 7; the Columbia axle,

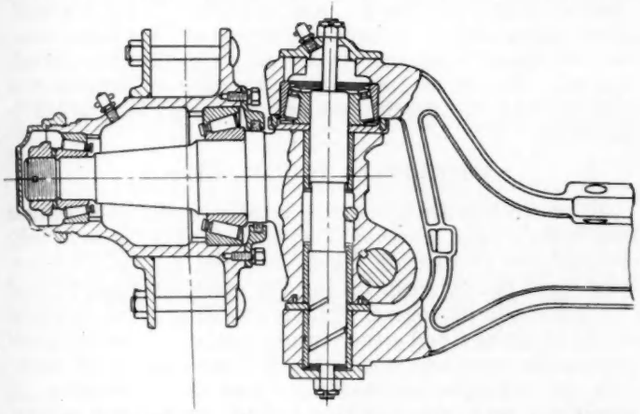


Fig. 9—The Steering-Knuckle Used on the Autocar Truck Which Makes Use of a Vertical Pivot

Fig. 8; and the Autocar truck-axle, Fig. 9. However, there are many advocates of the transversely raked pivot and, in particular, of a pivot that has its axis inclined so as to meet the road at the central point of tire contact. This type of construction, employed by Rolls-Royce, Fig. 10, and Metallurgique, Fig. 11, usually is, among others, referred to as "center-point steering" and has certain advantages that are worthy of careful consideration. These advantages include

(1) Road shocks in the plane of the wheel have a minimum moment about the knuckle-axis and, consequently, are transmitted in a less degree to other parts of the steering mechanism
(2) Wheels have a minimum tendency to toe-out, because the moment of rolling resistance about the pivot axis is at a minimum
(3) Possibly easier steering, although there is some question as to whether this actually is realized in practice

In an article by A. Ludlow Clayden, entitled Wheel-Wabble and Other Faults in the Steering-System, it is contended that advantage (1) is negligible. This contention has been refuted by O. M. Burkhardt in an article entitled Steering-System Stresses Reduced with Transversely Raked Pivots,[5] and by other persons. Road shocks on the steering mechanism undoubtedly are less by a considerable amount, but of course they are not eliminated. Some argue that, with center-point steering, the front

[4] See *Automotive Industries*, Oct. 5, 1922, p. 667.
[5] See *Automotive Industries*, Dec. 14, 1922, p. 1178.

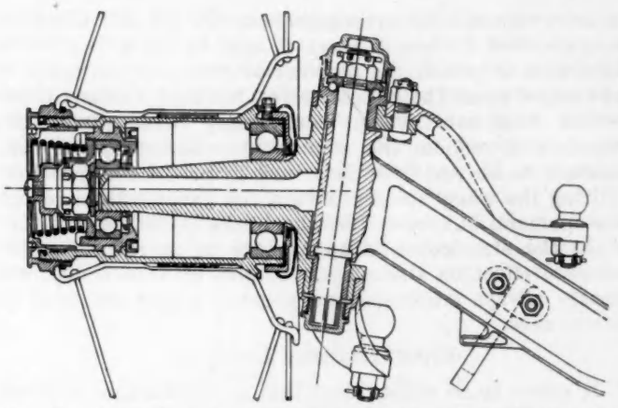


Fig. 10—The Rolls Royce Steering-Knuckle in Which the Pivot is Inclined to Give Center-Point Steering

end of the car is raised when the wheels are deflected from their straight-ahead position, a contention with which I am unable to agree. Since, with center-point steering, the wheel does not roll when it is cramped with the car standing, as it does with a vertical pivot, it seems doubtful whether a car with transversely raked pivot actually steers more easily than one with vertical pivots. With center-point steering the torsional stresses on axle and spring due to road shock are increased, but the design easily can be made such as to care for these. Clayden contends,[4] as pointed out elsewhere, that transversely inclined pivots involve an increased tendency to bring about wheel-wabble.

It undoubtedly is more difficult to manufacture axle and knuckle parts when transversely inclined pivots are employed; so, there is good reason to doubt whether, all things considered, the use of this construction is worth while except perhaps when front-wheel brakes are employed. In that case the possible stresses on the steering-gear and linkage are so great that inclined pivots are worth while if not actually essential. Examples of inclined pivots used with front-wheel brakes are shown in Figs. 11, 12 and 13, all of which are approximately or

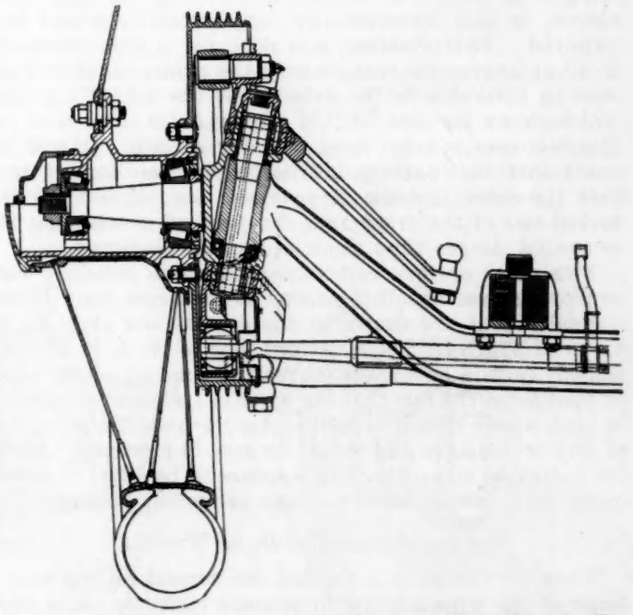


Fig. 11—A Good Example of the Knuckle-Pivot Layout Employed With Front-Wheel Brakes, That Used on the Metallurgique Car

exactly center-point arrangements. To put the matter in a somewhat different way, it can be said that it is desirable to reduce the moment of forces in the plane of the wheel about the knuckle-pivot, but that a construction which does not involve transversely raked pivots but which still reduces the moment in question a sufficient amount to be wholly satisfactory in practice is possible. Tilting the wheel spindle toward the ground helps reduce the moment, but excessive wheel-rake is not good, either from the standpoint of appearance or in respect to its adverse effect on tire wear. Angles of 1 to 3 deg. are nearly always employed and greater angles are used in some cases.

Knuckle-Pivot Location

It seems to be self-evident that it is desirable to bring the knuckle-pivot as close to the central plane of the wheel as is feasible without involving unnecessary expense, yet surprisingly little attention is given this point in some instances. In one case, that of a well-known and much-used American axle, it was found possible to bring the pivot closer to the wheel a full ½ in. by simply using countersunk hub-bolts and slightly altering the machine work on the wheel spindle. Incidentally, this simple change greatly improved the steering of the car.

Engineers who have given the matter of knuckle-pin location careful study seem to be agreed that an ideal position for the knuckle-pivot is in the central plane of the wheel. There are certain problems involved in so placing it, but they do not appear insuperable, especially for higher-priced cars and trucks. This arrangement is, in fact, used to a limited extent, and one of its advocates contends that the cost actually is less than when conventional practice is followed. However this may be, a design embodying this principle is worthy of careful consideration and easily can result in better steering qualities. The primary advantages of a construction such that the axis of the knuckle-pivot lies in the central plane of the wheel are that center-point steering is attained without a tilted pivot and all tendency toward wheel-wabble, except that caused by lack of balance of the wheel, is eliminated. The chief disadvantage of this construction, or at least that of one form which has been employed, is that unnecessarily large wheel bearings are required. This disadvantage does not apply, however, to all arrangements that embody the principle, as will be seen by reference to the drawing at the left of Fig. 14, which shows the construction employed for some time on Marmon cars but not used on later models. It will be noted that the bearings are no larger than normal, but that the wheel spindle is reversed and carried in the forked end of the front axle, the jaws of which must be somewhat deeper than those ordinarily employed.

Two other designs embodying the same principle but employing bearings that appear to be larger than those normally used are shown in the central and right-hand views of Fig. 14. These designs, due to W. J. P. Moore, embody certain advantageous features, among which may be mentioned the fact that the pivot is enclosed completely in such a way that it is well protected from the entrance of dirt or moisture and should be easy to lubricate. Also, the increased size of bearing appears to be offset to some extent by a simpler axle-end than commonly is employed.

Foregather or Toe-In of Wheels

When the design is such that the normal rolling-resistance of the wheels tends to produce moments about the knuckle-pivots, or when the wheels have undergather, one or both of which constructions are, I believe, universally employed, the wheels have a tendency to spread or toe-out. In fact, if set absolutely straight ahead with the vehicle stationary, they will toe-out more or less, depending upon the amount of play and spring in the parts stressed, and rapid tire-wear will result. To counteract this tendency, the front wheels are always set with a foregather of 3/16 to ½ in. Just how much of this foregather is eliminated due to the stresses of normal service I do not know. I have never seen data in this regard, but believe that, in most cases, the wheels are still foregathered to some extent, even at times when considerable resistance to rolling is present. Just why this should be desirable is not entirely clear, but it is supposed to add to tire life to create this condition. It can be said, however, that a tilted wheel tends to roll in a circular path instead of in a straight line, and that foregather of the wheels counteracts this tendency. There is certainly one position of the wheels at which resistance to forward motion is at a minimum. Any deviation from this position, either inward or outward, increases this resistance; so, too much foregather is as bad as having the wheels toe-out. So far as I am aware, there is no definite rule establishing the precise amount of foregather which is desirable.

Castering or Trailing Effect

When the knuckle-pivot axis is truly vertical, the vehicle has little if any sense of direction; that is, it acts only in response to steering forces imposed by the operator, who must usually keep feeling the steering-wheel to hold the vehicle to its course. If, on the other hand, the axis of the pivot be tilted either transversely or with its upper end to the rear, the vehicle has a certain sense of direction or self-righting tendency; that is, a tendency to straighten out when deflected from a straight course, except perhaps under certain extreme conditions. This is due to the fact that the weight supported on the pivot tends under the influence of gravity to fall to the lowest point that the mechanism permits, or to trail behind the central point of tire and road contact. This is usually termed castering action. There is still a castering action if the pivot be tilted forward, but the vertical force due to the weight of the car no longer trails behind the vertical force due to the pressure of the road against the tire. This anti-trailer effect creates a tendency for the wheel to reverse when the vehicle is in forward motion and pull the steering-wheel from the hand of the operator; it is precisely the same effect as is created by rearward motion of the vehicle when the pivot is tilted backward as in common practice, although Clayden[6] takes an opposite view.

Napier points out,[7] in his article entitled Castering Action, that there are other forces besides gravity that contribute to the castering effect when the car is in motion and the wheels are deflected from a straight course. These are centrifugal or inertia forces that depend upon the velocity of the vehicle and the radius of the curve it is describing. In respect to castering, Napier says further:

> It will inevitably be found that the greater the caster effect, the more pronounced will be the influence of each rut and bump in deflecting the car from a straight line; and a driver relying on caster effect would be ill-advised to expect his car without personal intervention to avoid the ditches, even on the straightest and widest of rough roads. It is true that, if a bump deflects the steering wheels and the car from one smooth portion

[6] See *Automotive Industries*, Oct. 5, 1922, p. 667.
[7] See *Automobile Engineer*, July 9, 1914, p. 223.

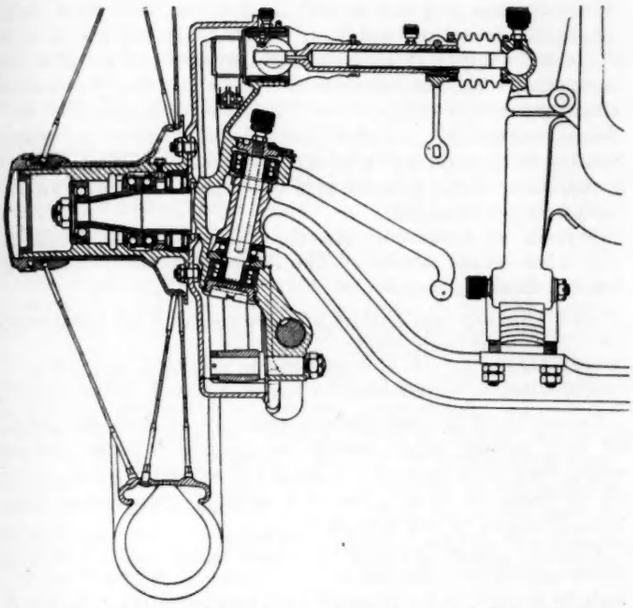


FIG. 12—ANOTHER EXAMPLE OF THE USE OF THE INCLINED PIVOT WITH THE FRONT-WHEEL BRAKE IS THE STEERING-MECHANISM OF THE DELAGE CAR

of the road to the next, castering action will give the car a tendency to follow a straight course; but it will not be the original straight course. . . . The tendency of castering action is not to preserve a straight course, but to restore the parallelism of the steering and driving wheels after the parallelism has been disturbed by whatever cause. It is, in fact, obvious that, since castering action must take place indifferently on either side of the center-line of the car, there can be no castering action while the car is proceeding in the direction of that center-line[8]. To my mind, the ideal form of steering-gear for a car intended principally for use on rough roads is the original Renouf type, the steering-pivots being vertical and in the planes of the wheels. This type has no castering tendency at any steering angle.

On a smooth and level road, castering action may be relied on.

While, on the level, by means of a judicious arrangement of steering details, combined with a skilful manipulation of speed in relation to curvature, a car may become self-steering so far as leaving a curve is concerned, it cannot automatically enter a curve from the straight.

The castering angle, or the fore-and-aft angle that the axis of the knuckle-pivot makes with the vertical, is usually from 1 to 3 deg., but angles as high as 6 deg. are employed. One experimenter, A. W. Werner, in a brief article entitled Steering-System Faults Explained,[9] states that angles of 4 deg. or more have resulted in violent wheel-wabble. He recommends making the caster angle equal to the angle of tilt of the wheel spindle, and states that 1¾ deg. is about the right value for both.

The castering angle is usually set by placing wedges between the spring and the spring-seat. It should be remembered that the castering angle sometimes varies with the deflection of either or both front and rear springs. The condition of average load should therefore be borne in mind in selecting the angle at which the pivot is set. One writer, in an article on Quarter-Elliptic

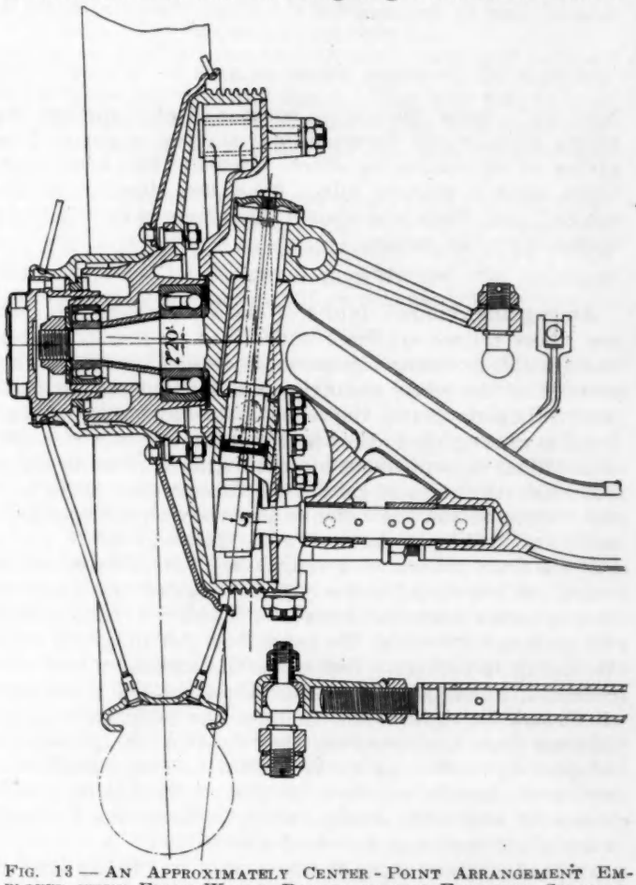


FIG. 13 — AN APPROXIMATELY CENTER-POINT ARRANGEMENT EMPLOYED WITH FRONT-WHEEL BRAKES IN THE EXCELSIOR STEERING-KNUCKLE

[8] This means, apparently, no castering effect other than that due to gravity.

[9] See *Automotive Industries*, Dec. 7, 1922, p. 1139.

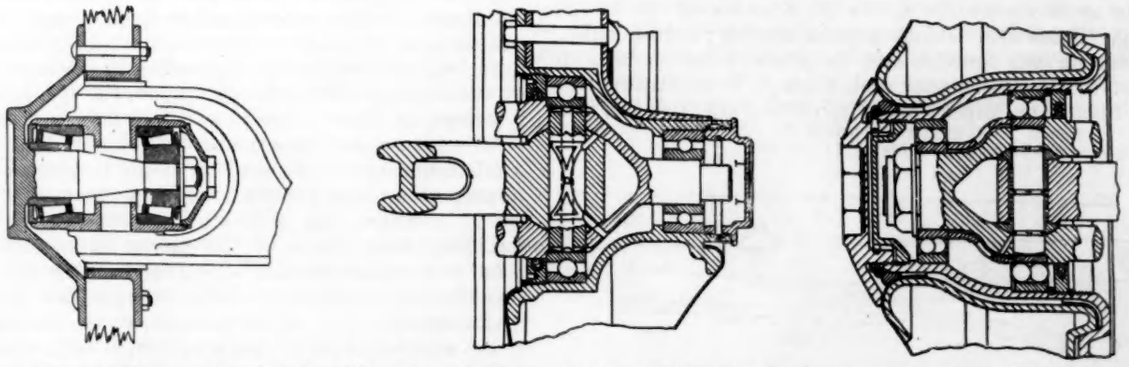


FIG. 14—EXAMPLES OF STEERING-KNUCKLE WITH THE AXIS IN THE CENTRAL PLANE OF THE STEERING-WHEEL
The Design at the Left Was Formerly Used on the Marmon Car, While the Other Two Were Suggested by J. P. Moore

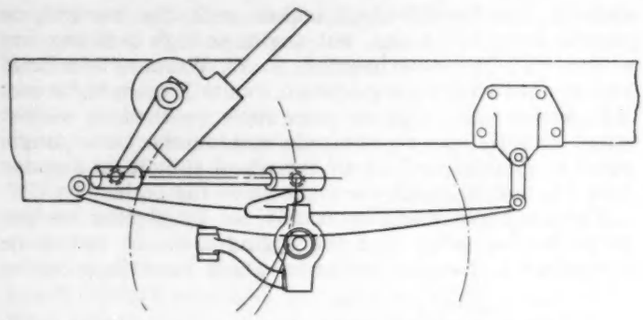


FIG. 15 — THE DRAG-LINK ARRANGEMENT INCORPORATED IN THE MACK TRUCK CHASSIS

Springs,[16] states that with quarter-elliptic springs the pivots tend to tilt forward in rounding a curve, thus giving an anti-castering effect. Items of this kind sometimes have a marked effect upon the steering of the vehicle, and therefore should be given close study in laying-down the design.

WHEEL-WABBLE

Among the common faults of the steering-system, and one whose causes are least understood, is that of wheel-wabble. This means the periodic oscillation in angular position of the wheel and axle spindle about the knuckle-pivot which results in the wheel following a course that deviates alternately to the right and the left of a straight line. When this phenomenon occurs, as it often does, in step with the natural period of the springs and front end of the chassis, the latter is given a violent transverse motion or shake popularly termed "shimmying."

If the front wheels of a vehicle be in equilibrium with respect to the knuckle-pivot in all angular positions of their spindles when the vehicle is in motion, wabble will seldom occur provided the layout of the drag-link and the spring is correct. But when the knuckle-pivots are inclined in either a transverse or a longitudinal plane, the wheels are in equilibrium in only one position and, if deflected from that position, they tend to swing back to and past it, oscillating in pendulum fashion unless the motion is damped-out by friction. Consequently, any chassis in which the knuckle-pivot is tilted has at least an incipient tendency to wheel-wabble.

Another primary cause of wheel-wabble is faulty layout of the drag-link in reference to the spring. If the drag-link is of rigid construction, or substantially so, and if the steering-gear arm is held rigidly, the end of the link attached to the knuckle-arm will swing through an arc when the front springs are deflected from their normal position. The axle-center is constrained, under the same condition, to move in a path that approximates an arc having as its center the eye in the unshackled end of the spring. These arcs seldom coincide exactly; consequently, the ball on the knuckle-arm is given some motion in respect to the axle center and, since it is constrained to move about the knuckle-axis, it causes the knuckle, the wheel spindle and the wheel to oscillate through a small arc, and the wheel wabbles. This is seemingly a self-evident fact, yet it is frequently overlooked or else the compromise chosen leaves much to be desired; for severe wheel-wabble is often caused by failure to consider this detail adequately. Cases have been known in which trucks have even suffered from broken frames or continually loosening engines and other parts due to a faulty layout in this regard.

Wheels or tires that are out-of-true or out-of-balance will also cause wobble. The three primary causes of wabble thus appear to be

(1) Unstable equilibrium of wheels carried on knuckles with inclined pivots
(2) Faulty layout of drag-links in reference to springs
(3) Lack of balance or failure of a wheel to run true

In addition, a considerable number of factors add to or help set-up wheel-wabble or render it more severe when once it is started. I shall not attempt to deal with all of these in detail, but will mention some that have been brought to my notice.

Friction tends to damp-out wabble, just as it does any other mechanical oscillation. Conversely, when it occurs, wabble is certain to be more pronounced when friction is at a minimum. This is why vehicles with loose or very free steering-connections are more apt to be addicted to wabble than those with joints set-up tight. Thus, wabble often can be stopped by tightening all steering connections, although it is a rough sort of remedy which, if not used with discretion, can result in excessive friction and rapid wear of parts.

The greater friction caused by under-inflated tires or increased weight on the wheels can easily damp-out wabble, and such items as anti-friction bearings on knuckle-pivots, better lubrication, loose-treaded tires and the like sometimes make wabble worse. This should not, however, be used as an argument against minimized friction in the steering-system, for it certainly is possible to have free steering without wabble if the system be well laid out and well constructed.

It is conceivable that wabble so slight as to be imperceptible to the operator can occur, especially if the steering-gear approximates the so-called irreversible type. It is clear also that any slackness or insufficient stiffness in any part of the steering-system or its supports, springs and spring parts included, which permits the wabble to take place through a greater amplitude than it otherwise would do, is apt to make the wabble more violent. Thus, a weak axle, frame or steering-gear housing, or insecure fastening of these members, will sometimes permit wabble that otherwise would not become evident. Much the same can be said of drag-links, tie-rods, tie-rod and knuckle-arms and steering-gear parts that are not stiff. Similarly, front springs that are weak or loosely fastened can help to amplify wabble; and weak springs in the drag-link will do likewise, as will also a whipping action of either drag-link or tie-rod. From the foregoing it will, I believe, be easy to see how wheel-wabble occurs.

It is not so easy to explain why violent shaking of the whole front end of the vehicle, which involves very heavy forces, sometimes results. To help clear up this point, let us consider the following. Suppose the wheel is wabbling, due to any of the causes enumerated, and is about to complete one deviation, say to the right. Suppose also that each time it reaches this position it strikes a road inequality that tends to accelerate its angular motion in the same direction; that is, an impulse in step with its natural period. It will swing still farther to the right, fetch-up short and be snapped back to the left, perhaps

[16] See *Automobile Engineer*, May, 1921, p. 162.

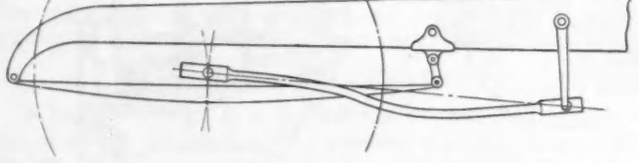


FIG. 16—THE DORT PASSENGER CAR USES THIS LAYOUT OF DRAG-LINKS

again receiving a blow from the road which accelerates it in that direction. Again it fetches-up and is again snapped back, building up a cumulative effect that can even become so violent as to put the car out of control. It is possible also that a physiological reaction from the arms of the driver can act as the force which accentuates wobble under some conditions. In any case, it happens sometimes that a car which is shimmying badly will cease to do so immediately if the driver releases his grip upon the steering-wheel. The freer the swing is and the greater the play in the linkage, the less damping-out there is and the more violent the shocks imposed in fetching-up in extreme positions will be. The front end of the frame, the engine, radiator and the like of course tend to follow the right-and-left oscillation of the wheels and, if the period is in tune with the natural period of the mass involved, the shake becomes exceedingly violent.

There are doubtless some gyroscopic forces involved in this wabble phenomenon. In this connection one commentator states that up-and-down motion of the spindle tends to induce a wabble of the wheel about an axis at right angles to the spindle. Another points out that a revolving wheel tends to resist deflection from its plane

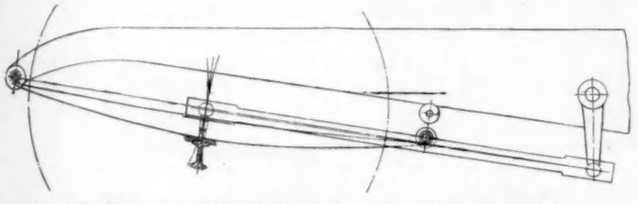


FIG. 17—THIS ARRANGEMENT OF DRAG-LINKS FORMS A PART OF THE DORRIS PASSENGER-CAR CHASSIS

of rotation; but that, once such deflection is started, only a small force will keep it oscillating. The amplitude of wheel-wabble that is caused by the lack of a perfect tie-rod and spring layout depends in part, at least, upon the length of the lever-arms involved. It is desirable to have the knuckle-arm connected to the drag-link as long as possible and still clear the spring, provided, of course, that it is made sufficiently stiff; for, the longer this arm is, the less will a given motion of its ball-end affect the course of the wheel. A long drag-link also has the advantage of swinging in an arc of less curvature than that of a short link.

DRAG-LINK LOCATION

It is customary for steering-gear makers to advise their customers to locate the gear so that the ball on the gear-arm, that on the knuckle-arm and the pin on the unshackled end of the spring are in the same plane, or in line as viewed in side elevation, when the vehicle is under normal load. This brings the drag-link approximately in line with the main leaf of the spring. Others contend that a somewhat different layout is better. It is agreed, however, that the best layout is that which causes the least motion of the wheel spindle about the knuckle-pivot when the axle is moved under the influence of spring action. At best, the layout is a compromise which requires careful study if ill effects are to be minimized. A number of layouts employed on modern passenger-car and truck chassis are shown in Figs. 15 to 19.

There are some advocates of a transverse as opposed to a fore-and-aft arrangement of the drag-link. One of these contends that it avoids the use of a crooked drag-link and, in most cases, gives a better layout, especially when maximum wheel-cramp angles are considered. Another engineer takes the view that a cross-type drag-link is not satisfactory with the usual spring-suspension, a

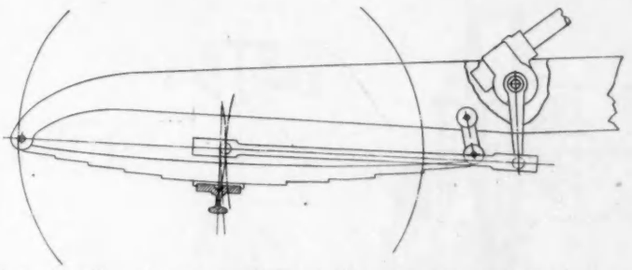


FIG. 18—THE DRAG-LINK LAYOUT INCORPORATED IN THE CHASSIS OF THE JORDAN PASSENGER CAR

contention that he says is readily borne out by studying the layout on the drafting board. This may well be true in some instances, but it is evident that each case must be considered on its merits and the best compromises selected.

On some short-wheelbase passenger-cars and on trucks in which the driver's seat is well forward, a transverse drag-link arrangement is often satisfactory. The frame must, however, be designed to withstand the twisting stresses that such a layout will sometimes impose.

IRREVERSIBILITY

There is much loose talk concerning the so-called irreversible steering-gear but, so far as I am aware, there is no such thing used as a completely irreversible steering-gear, nor does it seem desirable to employ such a construction, even though it should prove feasible to produce it. Perhaps the closest approach to an irreversible gear are the worm-and-wormwheel, or the worm-and-segment types. With these types the steering-wheel can be moved by applying a steady side-pressure on the road wheels, proving that gears of this type are not irreversible; but a sudden shock tending to deflect the road wheels from a given position has a tendency to cause such a gear to become momentarily irreversible or self-locking. This probably is due to the fact that the lubricant is momentarily forced from between the relatively small contact surfaces of worm and wheel, or segment, thus increasing friction and preventing the turning that would occur otherwise. On this account gears of these types are practically irreversible under shock, which is precisely the condition under which irreversibility is held by some to be desirable.

So far as I am aware, all other types of gears are reversible more readily than the worm-and-wheel and the worm-and-segment types and are therefore, for the same reduction-ratio and steering-system layout, more apt to permit any shock tending to deflect the road wheels to be transmitted to the steering-wheel. So, engineers take the view that it is not desirable to have the steering-gear approach closely the self-locking condition because, when so made, the linkage and bearings between the steering-gear and the wheels are stressed more heavily when shocks are imposed.

When the gear is free enough to transmit the motion caused by the shock to the steering-wheel, some of the

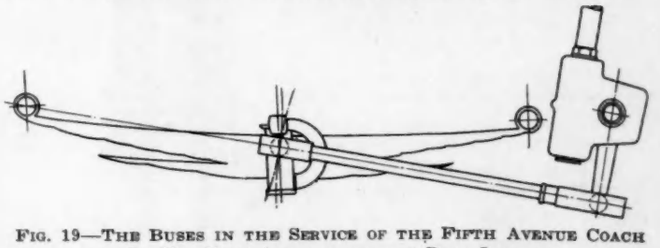


FIG. 19—THE BUSES IN THE SERVICE OF THE FIFTH AVENUE COACH CO. USE THIS ARRANGEMENT OF DRAG-LINKS

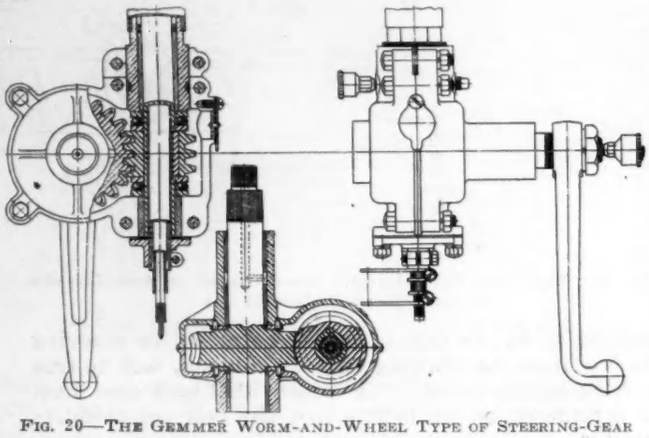


FIG. 20—THE GEMMER WORM-AND-WHEEL TYPE OF STEERING-GEAR

energy of the shock is dissipated in the mechanism of the gear, thus bringing about a certain cushioning action which is advantageous. If, however, the motion on the steering-wheel becomes excessive, it is much less comfortably handled by the operator. Those who favor the comparatively easily reversed type of gear are apt to favor also a center-point steering-arrangement which, as pointed out elsewhere, tends to eliminate shocks in the plane of the wheel, the kind of shock most frequently encountered. All things considered, it is probable that a certain degree of reversibility is a desirable thing, but clearly it is not desirable to employ gears that are so easily reversible as are those used in some present-day cars.

COMPARISON OF STEERING-GEAR TYPES

The following types of steering-gear are in more or less general use today:

(1) Worm-and-wheel and worm-and-segment
(2) Screw-and-nut, including differential-nut types
(3) Bevel-gear
(4) Planetary-gear
(5) Spur-gear-and-rack
(6) Cam

It is impossible to consider here all of the advantages and disadvantages of the various types, especially since it is not always easy to differentiate between advantages inherent in a type and those that are dependent chiefly upon a particular embodiment of it. When well proportioned and well lubricated, the worm-and-wheel type has excellent wearing qualities, even though the bearing area between the worm and the wheel is rather small. If, however, lubrication fails, considerable friction and rapid wear are apt to result. A disadvantage of this type is that it is practically impossible to take up any lost-motion caused by wear although, when the full wheel instead of a sector is employed, the wheel can be moved successively to four different positions 90 deg. apart, thus compensating for wear in the wheel but not for wear in the worm. It can be said, however, that well proportioned and well made gears of this type wear almost indefinitely, provided they are kept well lubricated; so, the disad-

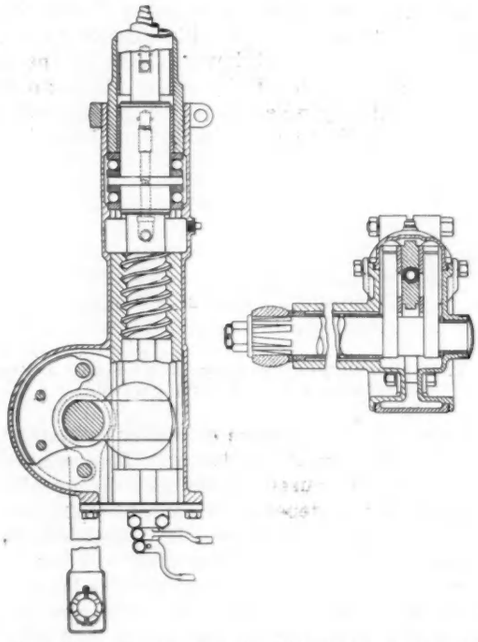


FIG. 21—THE ROSS SCREW AND NUT TYPE OF STEERING-GEAR USED BY THE AUTOCAR CO.

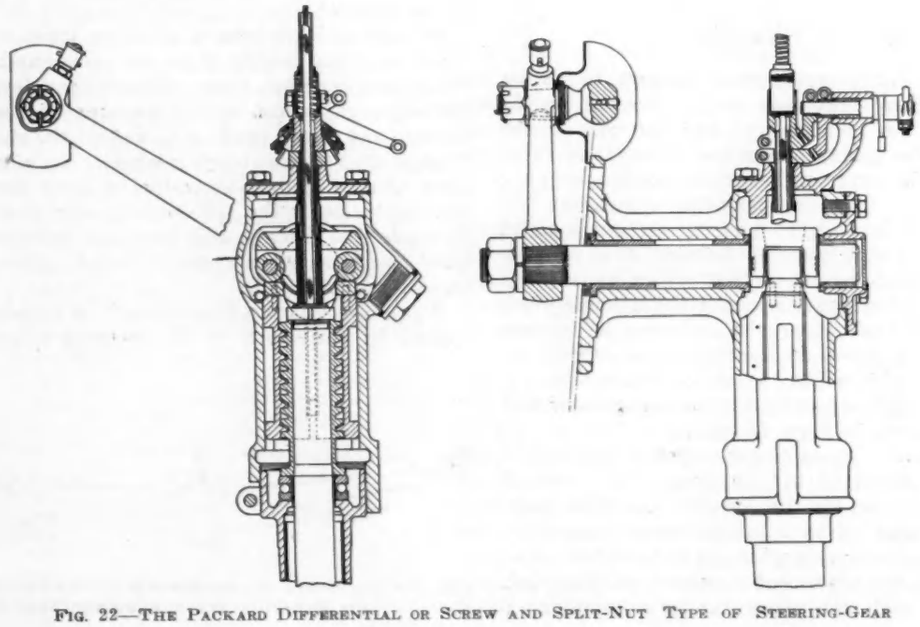


FIG. 22—THE PACKARD DIFFERENTIAL OR SCREW AND SPLIT-NUT TYPE OF STEERING-GEAR

vantage cited can be made relatively unimportant. Examples of the worm-and-wheel type of gear are shown in Figs, 5, 6 and 20.

One of the most widely used types of steering-gear is the screw-and-nut type, which is generally regarded as being very satisfactory when well made. A good example of this type is the Ross gear, in the form used by Autocar, shown in Fig. 21. The chief advantage of this type is good wearing quality due to the large bearing surface between the screw and the nut, and its chief disadvantages are its lack of adjustability and rather high cost of manufacture when the nut is well fitted to the worm. It can be said, however, that adjustment is seldom required provided, again, that lubrication is cared for properly. Alternative constructions of the same general type are used to overcome the disadvantage of non-adjustability just cited. In one of these the nut is made in two halves, one having a right and the other a left-hand thread, so that they move in opposite directions. This differential movement is transmitted to the steering-lever shaft by a mechanism that can be adjusted easily to take-up all lost motion. An example of this type of construction is the Packard gear shown in Fig. 22. In another make, the right-and-left threads are cut on the inner and outer surfaces of a sleeve, and the nuts or outer and inner mating parts are arranged to transmit their motion to a shaft on which the steering-arm is carried

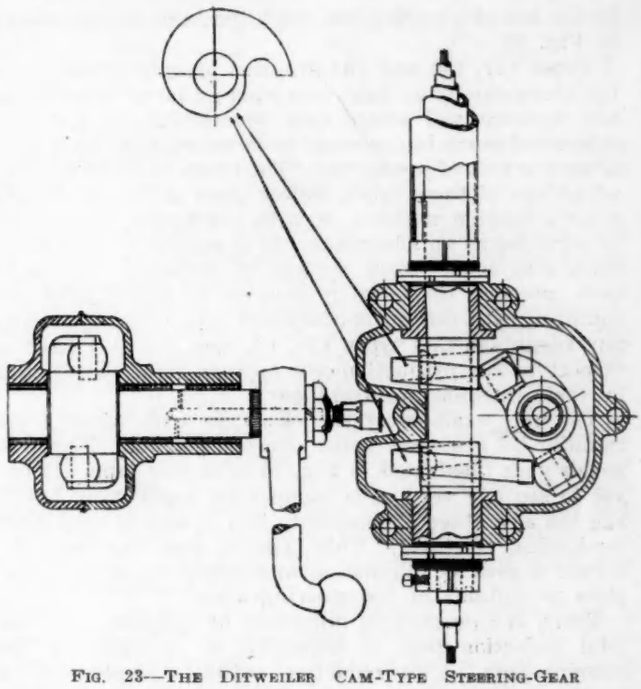


FIG. 23—THE DITWEILER CAM-TYPE STEERING-GEAR

TABLE 1—DETAILS OF DIFFERENT TYPES OF STEERING-GEAR

	NAME OF CHASSIS															
	PASSENGER CARS									TRUCKS					BUS
Steering-Gear Details	Crane, Experimental	Dort, Model 25	Durant, Four	Franklin	Jordan	Marmon Model 34	Oakland, 6-44	Packard, Single-Six	Rolls-Royce 40-50	Autocar			Mack, 5-Ton	Service, 52	Fifth Avenue Coach Co.
Approximate Weight on Front Wheels, lb.	2,700	1,300	.....	1,320	1,450	1,550	500	1,550	2,000	3,500	4,500	5,500	6,280	3,525	6,590
Transverse Rake of Knuckle, deg.	0	1	0	0	.....	0	0	0	5	0	0	0	2	1½	0
Lateral Rake of Knuckle, deg.	1 to 2	½ to 1	3 to 5	6	4¼	4	6	3	1	2	2	2	2½	4	0
Type of Knuckle-Pivot Bearing	Roller and Plain	Phosphor Bronze	Bronze	Steel	Plain	Plain and Ball	Bronze	Plain	Plain	Roller and Plain	Roller and Plain	Roller and Plain	Plain	Roller and Plain	Bronze
Inside Diameter of Knuckle-Pivot Bearing, in.	.....	¾	¾	11/16	¾	1½	1	¾	1	1⅛	1	1⅛	1¾	1⅛	1⅛
Toe-In of Wheels, in.	¼ to ⅜	⅜	⅜ to 1/16	¼	¼ to ⅜	1/16	1/16 to ⅜	¼	½	⅜	⅜	⅜	⅜	⅜ to ½	0
Type of Steering-Gear	Worm and Wheel	Screw and Nut	Worm and Wheel	Worm and Wheel	Worm and Wheel	Screw and Nut	Screw and Nut	Worm and Wheel	Screw and Nut	Screw and Nut	Screw and Nut	Screw and Nut	Worm and Wheel	Screw and Nut	Screw and Nut
Reduction in Steering-Gear	29 to 3	7.50 to 1	7.50 to 1	6 to 1	7.50 to 1	9.50 to 1	7.80 to 1	9.45 to 1	9 to 1	8	12	15	12 to 1	12 to 1	10 to 1
Outside Diameter of Steering-Wheel, in.	18	16¾	16	18	17	18	17	17	17	18	18	20	20	20	18
Number of Wheel-Turns from Locked to Locked Position	1½(a)	1⅞	1¾	1½	2¼	1 11/16	1⅝	1 7/16	1⅝	1½	2	2½	1¾	1¼	1½
Length of Steering-Arm, Center to Center, in.	10½	8 11/16	5	5⅝	8	8 1/16	8½	8	9	6¾	8	9	9	7⅜	9
Maximum Angular Motion of Knuckle-Arm, deg.	45(a)	71	83	78	60½	67¼	80	65½	65	67½	70	73	61	38	59
Length of Drag-Link, Center to Center of Balls, in.	40	32	30⅝	23¼	23 11/16	33 1/16	15½	29	46	35¾	30¾	31	16	21¾	45
Distance from Spring-Horn Pivot to Center of Ball on Knuckle-Arm, in.	20	18½	(c)	18¾	16	17	15½	19¼	22	(c)	(c)	(c)	22⅞	19½	23 1/16
Approximate Maximum Motion of Front Spring, in.	6 to 7(b)	1½	4 to 5	6	4	2¾	4	6	6	4	4½	4¾	2 1/16	.....	2
Maximum Angular Motion of Steering-Gear Arm, deg.	.....	70	84	90	92½	71	75	65½	52	60	60	60	65	37	54
Length of Steering-Knuckle Arm, in.	8	6⅝	5⅛	7⅝	6½	8 1/16	8	8	7¼	.....	.....	.....	8	6½	8 1/16

(a) Approximate. (b) No load to bottom. (c) Transverse drag-link.

by the use of a mechanism much the same as that shown in Fig. 22.

Types (3), (4) and (5) are used by only a few manufacturers, chiefly on light cars where a large reduction is not required and where easy reversibility is not considered of much importance, or is outweighed by a relatively low cost of production. The latter is about the only advantage of these types, unless their ability to operate after a fashion without, or with indifferent, lubrication is regarded as an advantage. It is worthy of note, however, that some recent designs of American passenger cars intended for large production at a low price are equipped with the worm-and-wheel type of gear, so that any advantage that types (3), (4) and (5) may have in respect to low production-cost appears to be outweighed by their inherent disadvantages.

The only example of the cam type with which I am familiar is produced under Marles patents. The Ditweiler gear illustrated in Fig. 23 is of this type. It has yet to see any very wide commercial application, but it has the advantage of simplicity and is said to have high mechanical efficiency. This type of gear has been designed to give its full motion with either one or two complete revolutions of the steering-wheel.

There is considerable difference of opinion as to the total reduction that is necessary or desirable in the steering-gear. This reduction naturally depends to a great extent upon the weight of the car and the mechanical efficiency of the mechanism employed. The reduction ordinarily used on passenger cars varies from 6.0 to 1 to 9.66 to 1, and the number of revolutions of the wheel necessary to move the road wheels from locked to locked position varies from 1.5 to 2.25.

There are certain advocates of rather "fast" steering-mechanisms; that is, mechanisms which require a relatively small angular motion of the steering-wheel for a given angular motion of the road wheels. Others prefer a "slower" gear, or one with a greater reduction, even though this type does not respond so rapidly to the demands of the operator. Other things being equal, the slower the steering is the less are shocks on the road wheels transmitted to the steering-wheel, and vice versa.

Tie-Rod Arms and Tie-Rods

Tie-rod arms should be as stiff as weight and manufacturing considerations admit. If yoked tie-rod ends are to be employed, it is important to see that the axes of the holes in the yoke pins are truly parallel to each other and to the knuckle-pin axes; otherwise, if the yoke pin is well fitted, binding will occur in some positions. If the knuckle-pivot axes are not intended to be parallel, as in the case of transversely raked pivots, it is necessary to use a ball-joint or its equivalent between the ends of the tie-rod and the tie-rod arms to prevent binding in the mechanism.

One prominent designer states that it is practically impossible to fit yoked tie-rod pins tight enough to prevent rattle and still avoid binding. Even though the knuckle-pivot and yoke-pin axes be made truly parallel in machining, they are certain to be thrown somewhat out of this relative position when the axle is deflected, as it always is to some extent under normal load. For this and other reasons a ball-and-socket joint such as is used on the ends of the drag-link has important advantages. Some engineers consider it safer than the ordinary yoke construction. The springs back of the bearing-blocks afford a certain cushioning action against shock which, if the springs are proportioned properly, is highly desirable. An unusual design of ball-and-socket tie-rod end is used in the Excelsior design as will be seen from an examination of Fig. 13.

A rather common and serious fault of some of the cheaper cars and trucks is the use of tie-rod yokes that are fitted poorly to begin with, and that have a totally inadequate means for locking them in position. The tangent bolt employed is frequently too small, and the shank of the yoke is not split far enough or with a wide enough slot to insure secure locking. As a result, the yoke soon rattles loose and becomes a source of danger. When the tie-rod is of tubular section, and especially when the walls of the tube are thin, care must be used to see that sufficient metal remains at the base of the thread to prevent failure under constant vibration. A yoke clamped to the tube by a tangent bolt sometimes compresses the tube under the influence of road shocks, and the yoke loosens on this account. This fault has been remedied in some cases by the use of a tight-fitting metal-plug, somewhat longer than the threaded portion, forced into the ends of the tube. There are some advantages in the use of a lock-nut against the inner end of the yoke-shank instead of a tangent bolt, but close-fitting threads are very important in this case.

Data on steering-gear details employed on different types of chassis are presented in Table 1.

The Discussion

Cornelius T. Myers:—Of the multifarious compromises that must be effected in automobile chassis design, those that affect the steering mechanisms are of great importance and worthy of much careful study. Many an otherwise clean piece of automobile architecture can be more or less severely criticized when the steering layout is carefully analyzed. These mechanisms constitute a really large problem in chassis design, because they must not interfere with the many others in front of and just behind the dash; they must be easily assembled and dismantled, they should afford the maximum of access to and for dismantling adjacent parts and, most important of all, they must afford safe and sure control of the direction of the car at all times.

In respect to safety, effective brakes rank first in importance and steering mechanisms a close second.

A recent editorial in *Automotive Industries* referring to the violent wabbling of the front wheels under certain conditions, has turned the spotlight on steering mechanisms by asking the question, "what makes 'em shimmy?" What this expression lacks in dignity it gains in pertinence; and it is gratifying to note that there is no lack of opinion among the engineers of the industry as to the cause and its cure, which should be readily effected.

Having listened to and read with great interest the views of several well qualified to speak on the subject, I offer to the discussion two or three explanations not heretofore advanced, and which it is hoped will be of some service.

First: A feature of major importance in the layout of a steering mechanism is the relation of the path of travel of the *ball* on the steering-knuckle arm when under the influence of spring vibration, to the position of the ball on the arm of the steering gear itself.

Figs. 24 and 25 are typical layouts showing two lines of travel for the steering-knuckle ball, and the axle itself as the springs deflect. The axles, with their knuckle-pivots, follow the lines xx due to the flexure of the springs. The balls on the steering-knuckle arm in each case follow approximately the arcs yy that have for centers the centers of the balls on the steering-gear arms.

It is seldom that these two arcs coincide for any appreciable distance, and in some cases, as in Fig. 24, they diverge considerably as the axle is raised or lowered with respect to the frame when the springs flex. In looking at the Figs. 24 and 25 note that the arc xx in each case is the path of the center of the ball on the steering-knuckle arm provided the steering-knuckle is held so that it cannot turn about its pivot, and provided the ball is not connected to the steering-gear arm by the drag-link.

But actually the ball cannot follow this path because it is connected by the drag-link to the ball on the steering-gear arm. It must swing, in a vertical plane, through an arc centering about the ball s on the pitman arm of the steering gear, and also in a horizontal arc about the center of the steering pivot on the axle.

Referring now to a plan view, Fig. 26, p and q are the steering pivots held by the ends of the axle, b is the ball

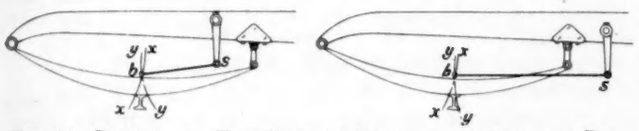


FIG. 24—DIAGRAM OF TWO STEERING-SYSTEMS SHOWING THE RELATIVE POSITIONS OF THE SPRING AND THE DRAG-LINK AND THE STEERING-ARM

on the steering-knuckle arm of the axle and is connected by the drag-link to the ball s on the steering-gear arm and c and d are the clevis pivots at the ends of the tie-rod.

Assume that the left wheel, striking a bump, rises. The point p on the axle, traveling along the arc xx in the left portion of Fig. 24, reaches the point p_1, Fig. 26. The ball b on the steering-knuckle arm moves along the arc yy, in the left portion of Fig. 24, and reaches b_1, Fig. 26. Thus the wheel spindle which was normally in the position pm, now takes the position p_1m_1, and the clevis c moving to c_1 changes the position of the right wheel spindle from qn to q_1n_1. Thus with the steering layouts, as in Fig. 24 and the right half of Fig. 25, any rise of the left wheel will tend to turn the car to the left and a fall of the left wheel will tend to turn the car to the right. With a layout as in the left half of Fig. 25 this action will be modified and much diminished, the car tending to turn to the right whether the left wheel rises or falls.

Under certain road and speed conditions this action will cause the wabbling and resultant "shimmying" to which reference has been made. Some cars have a greater tendency to wabble than others, due largely, as will readily be seen, to the varying rates at which the paths xx and yy diverge in any particular steering layout.

Second: The other feature bears on the first one, just demonstrated, and in my experience it accounts for the astounding violence of this wabbling at times. Wabbling seems to be the greatest when there is a very perceptible amount of wear in the steering-pivot bushings, wheel bearings and other points of wear or possible looseness. When successive bumps or depressions in the road surface synchronize with the taking up and giving out of the total amount of wear or slack, the wabbling seems to be most severe. It is somewhat analogous to snapping a whip, or more directly to a chain in which the links are long in proportion to their width. The end links suddenly reverse their direction of motion when the chain is snapped like a whip, for they receive a violent check when, having attained some velocity, the slack suddenly reaches its limit and the reaction causes a partial reversal. If the grasped end of the chain is reversed at the right moment the free end can be kept swinging from side to side in a regular period of vibration. The

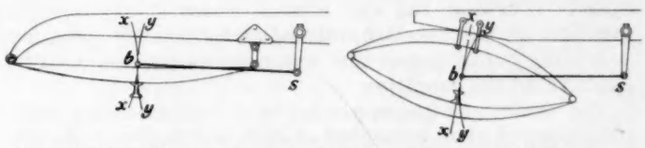


FIG. 25—TWO OTHER STEERING-SYSTEMS HAVING VERY DIFFERENT ARRANGEMENTS OF THE SPRING AND THE DRAG-LINK AND THE STEERING-ARM

stresses in the chain will be greatly increased if a weight is attached to the free end, and the analogy of the return ball on a rubber cord is also apparent.

In an automobile the links of the chain are the various parts and their connections, namely: Wheel-hub bearing races, axle spindles, steering pivots and their bushings, the various pins and links in the steering mechanism, the spring bolts and their bushings. The ball on the end of the "chain" is the front end of the frame with engine, radiator, etc.; or the engine itself, if it is at all loose on its fastenings. When a series of road bumps synchronizes with the vibration period of the springs, and this period is some harmonic of the whipping "chain" of loosely connected parts, "she shimmies," and sometimes with a vengeance.

Third: A point on which I am still experimenting, is the influence of the unbalanced forces set up in the front wheels by the weight of the tire valves and adjacent parts. Due to the fact that the wheel spindles are not horizontal, these unbalanced weights move from and toward the chassis as the wheels revolve.

It would appear that when the position of the valve in the left wheel bears a certain relation to the position of the valve in the right wheel, the forces set up as these valves revolve will counteract and tend to balance out. On the other hand, the relative location of the two valves might be such that the two forces were additive.

If there is looseness in the steering pivots and connections, and the speed of rotation of the wheels is such that these forces act in harmony with the "whipping chain" mentioned above, it seems altogether possible that they can either produce and intensify wabbling or intensify it when produced by some slight road inequality. I have known bad cases of wabbling to start on comparatively smooth concrete roads when the car was driven in one direction, but no wabbling occurred when driving over the same stretch in the opposite direction at the same

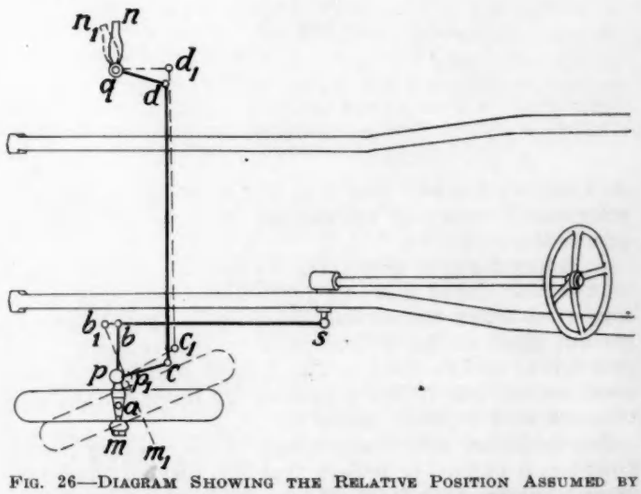


FIG. 26—DIAGRAM SHOWING THE RELATIVE POSITION ASSUMED BY THE PARTS OF THE STEERING-SYSTEM WHEN THE WHEELS ARE IN THE STRAIGHT-AHEAD POSITION INDICATED BY THE FULL LINES AND WHEN TURNED AS INDICATED BY THE DOTTED LINES

speed. Turning the car around changed the relative position of the two-tire valves, and evidently caused a balancing out of forces that had previously promoted and aggravated the condition.

The conditions under which the violent wabbling takes place depend upon a number of different factors; (*a*) the steering layout, (*b*) the inequalities of the road, (*c*) the vibration period of the springs, (*d*) the speed of the car, (*e*) the weight of the front end of the car, (*f*) its moment of inertia about a vertical axis, (*g*) the tire inflation, and (*h*) wear and looseness of front axle and steering-gear parts, etc. It is not easy to simulate these conditions, and often minor changes of one kind or another seem to cure the trouble; but it is latent if the steering mechanism is not correctly laid out, and will reappear under somewhat different conditions than at first.

In driving a car which has a recurrent tendency to wabble badly, I have found that turning steadily and not too sharply to one side or the other will check the phenomena if it is not allowed to become too violent. As a rule it is best to drive on the right side of a crowned road so that one must continually exert a little left-arm pull on the steering-wheel to keep a straight course. This takes the slack out of loose steering connections, and obviates any wabbling due to looseness only. A further turning toward the left or crown of the road will take up any slack produced when wabbling is started by impressed vibration from road bumps, and will often damp out the wabble before it becomes severe.

In *Automotive Industries* an article appeared entitled Wheel Wabble and Other Steering System Faults, by

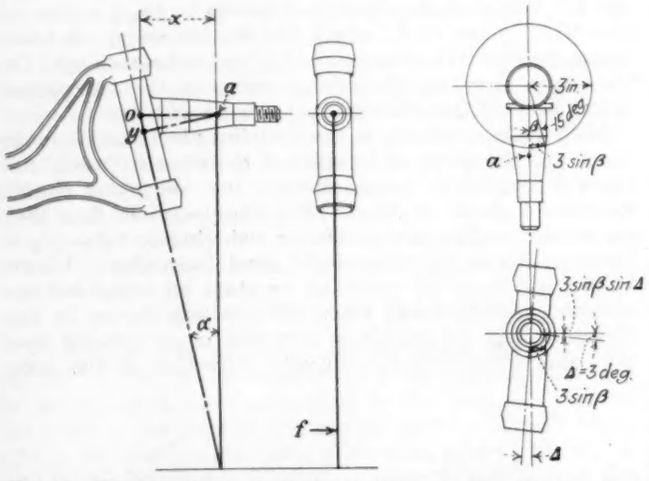


FIG. 27—DIAGRAMS ILLUSTRATING THE EFFECT OF THE TRANSVERSELY RAKED STEERING-PIVOT AT THE LEFT AND AT THE RIGHT THE SMALL AMOUNT OF SPRING MOTION OCCASIONED BY A SLIGHT REARWARD RAKE OF THE STEERING-KNUCKLE PIVOT

A. Ludlow Clayden[11] who sets forth several points with reference to steering mechanism that can certainly be given close attention.

It is particularly gratifying to note his denial that a transversely raked steering pivot makes for easy steering, even when the extension of its axis touches the ground plane at the central point of tire contact. This practice is seldom used in the United States, and with good reason, but it has a number of foreign adherents who are loud in their claims for it.

In connection with transversely raked steering pivots, however, it is hard to believe that Mr. Clayden is correct when he states that front wheels are in unstable equilibrium when they are pointed straight forward; also when he states that with the drag-link disconnected the wheels would swing against the frame of the car either in one direction or the other. Referring to the drawing at the left of Fig. 27, the point *a* on the spindle, whether the wheel is turned in or out, moves in a circle the plane of which is perpendicular to the axis of the steering-spindle. Thus, no matter in which direction the car is turned, in the view shown, the point *a* moves along the line *ay* perpendicular to the axis of the steering pivot. This movement tends to lower the wheel and raises the car, so that the front wheels, uncontrolled by forces exerted through the steering mechanism, tend to point straight forward and become stabilized in that position, under the influence of the weight of the car. Cars with such a steering mechanism have a considerable tendency to be self-righting, but with any looseness in pivot bushings and steering connections, the wheels can set up a violent and persistent wabbling once the right conditions are encountered.

Mr. Clayden's theory, that the tendency to raise or lower the wheel when turning the car, due to a fore-and-aft raking of the steering pivots, is the primary cause of wabbling, is an interesting one and worthy of close study. That the use of vertical pivots will always cure the trouble is doubted, however, as wabbling has been noted in cases where the pivots were vertical.

There seems to be much more likelihood that the interaction of springs and steering leverages is the primary cause of the trouble, and that this is aggravated by loose connections. Mr. Clayden's statement that increased friction in the connections prevents wabble is in line with the view expressed in the second item in this discussion.

As to a comparison of effects on wheel wabble of rearwardly inclining the pivots as opposed to the spring action, Mr. Clayden states that, due to inclining pivots, one wheel may drop and the other rise perhaps ¼ in. in making a turn of minimum radius where the inner wheel is cut say 30 deg. from straight forward position. A 30-deg. swing does not occur in wabbling. Five degrees is about the average on either side of neutral position, unless there is a considerable looseness in the connections, and 15 deg. is perhaps a maximum, giving a total swing of 30 deg. from extreme to extreme.

Assume that the knuckle pivot is located in a vertical plane, according to the usual American practice, and not inclined transversely toward the frame. The average rearward inclination of the steering-knuckle pivot is less than 3 deg. = angle Δ. Taking the distance x in the drawing at the left of Fig. 27 as 3 in. we have the rise or fall of each wheel = 3 sin β sin Δ (See the drawing at the right of Fig. 27.) Where β = 15 deg. we have a movement = 3 x 0.250 x 0.052 = 0.039 in., which is only one-sixth of the ¼ in. mentioned by Mr. Clayden. This is hardly enough to account for the wabbling, as the corresponding force must be applied through a reduction of about 20 to 1, thus in moving up or down this 0.039 in. the point *a* has circled a distance of

$$(2\pi \times 3 \times 15) \div 360 = 0.7854 \text{ in.}$$

and

$$0.7854 \div 0.039 = 20.2$$

The point *a* in moving about ¾ in. bends to compress the spring about 0.04 in. If the stiffness of the spring is 400 lb. per in. the measure of the compression due to the movement of *a* is about 16 lb. If this is reimpressed by the spring on the steering-knuckle it cannot be more than

$$16(0.039/0.785) = 0.79 \text{ lb.}$$

[11] See *Automotive Industries*, Oct. 5, 1922, p. 667.

or less than 1 lb. at the point *a*. Even this will be considerably reduced because of the friction losses in the spring leaves, in the pivot bushings and thrust bearings.

While it may be true that even this feeble effort tends to impress a wabbling motion to the wheels, it would appear to be unlikely that it is the real cause of the trouble. On the other hand, even a small divergence in the arcs *xx* and *yy* develops forces which are applied by direct and powerful leverages, and can reach a considerable intensity under conditions of synchronous vibration. This has been confirmed, in my experience, by the fact that wabbling has never occurred when only the right-hand wheel was encountering a series of road waves that would sometimes cause the wabbling if the left wheel passed over them. As the cars were left-hand steer, bumps under the right-hand wheel had but little effect on the left-hand steering arm that was connected to the drag-link.

Placing the steering spindle in the middle plane of the wheel, as advocated by Mr. Clayden, will not obviate wabble if the steering layout is faulty, and such a design has some serious drawbacks.

To obviate wabble

(1) Steering mechanisms must be laid out so as to prevent an appreciable angular movement of the knuckle steering-arm when the spring flexes

(2) Steering pivots should be ample in size and the bushings spaced as widely as possible so as to minimize bearings loads

(3) Provision for continuous lubrication of pivot and tie-rod bushings must be provided so as to prevent wear.

PROF. E. P. WARNER:—There is some danger of our overemphasizing the effect that mechanical play may have in connection with wheel-wabble and the "shimmying" of the car. To indicate how bad a wabble we can get without any possibility of mechanical play, we can turn to a vehicle in which wabble does appear very badly although the steering-gear is rigid throughout; that is, to a motorcycle, a bicycle, or other hand-steered vehicle of a similar type. As some probably know from experience, on a motorcycle at high speed, even on a smooth road-surface, a terrific wabble sometimes arises. That is sometimes experienced also on bicycles that do not have a spring-fork. It is reported that one of the British "scooters" of recent design, a vehicle with a rigid steering-column and a platform on which the driver stands, wabbled so badly as to be absolutely out of control at all speeds above 12 m.p.h. In at least three cases of which I have seen reports recently, that tendency to wabble, which was terrifyingly bad in the original machine, was cured by changing the curvature of the fork, which, of course, is equivalent to changing the castering of the wheel.

Do the figures for the reduction-ratio in Table 1 of the paper relate to the reduction in the gear itself or to the total reduction from the steering-wheel to the road-wheel?

HERBERT CHASE:—The figures given in the table are the answers to a questionnaire on the "reduction in the steering-gear." I am not certain what was understood by this, but believe that in most cases the information given applies to the actual reduction in the gear alone.

M. C. HORINE:—Mr. Chase mentioned the use of anti-friction bearings as a means of reducing friction in the steering-system. Does he mean to include the steering-knuckle pins in that category? Does he find that the use of anti-friction bearings in king-bolts is a good thing? It seems to me that an anti-friction bearing is fundamentally something made to turn, having point or line contact. If placed on a very slowly and only occasionally oscillating member, such as a steering-knuckle pin, the tendency would be for the balls and rollers to embed themselves in their races and produce hard instead of easy steering. Is it not true that center-point steering would really make it more difficult to steer, particularly at low speeds or when the vehicle is stationary, due to the fact that it is harder to grind the wheel about on a point instead of rolling it about a point?

It has been a source of amazement to me for a number of years that mystery as to the formula for foregather seems to be prevalent only in the automotive industry. The rules for wheel-setting are rather well established and well known in the horse-vehicle industry. The setting of the ordinary horse-vehicle axle is governed by well defined laws. It might be well for the Research Department to investigate them.

Another point that may not have anything to do with wheel-wabble but certainly relates to steering-gears, is the very general practice on the part of automotive manufacturers of using a standard front-axle for several different wheelbases. That is particularly true in the truck industry, in which there is a considerable range of wheelbase options on a chassis using one standard axle. In the case of assembled trucks, an axle is built for a large number of vehicles having different wheelbases, the tie-rod arms being placed at a certain angle. That angle is not changed for the different wheelbases. If we study the Ackerman system, we find that the accuracy of steering, even as to the turning-radius and certainty as to the tire wear, is very largely affected by the angle of the steering-arms.

In connection with the proper layout of the steering-gear, one point that has been rather stressed is the position of the drag-link, assuming that to be of the fore-and-aft variety, to achieve the minimum divergence of arcs as between the motion of the front axle about the fixed point of the spring and the motion of the drag-link about the presumably fixed position of the steering-gear arm. Mr. Chase illustrates in Fig. 15 a type of mounting wherein the steering-gear is located in front of the axle instead of behind it. That is not exclusive to the make he mentions, but is used by three American companies and also by a number in England. Has Mr. Chase any data concerning it?

Concerning Mr. Myers' assertion that, in the matter of safety the brakes come first and the steering-gear second, would Mr. Myers prefer to find himself in traffic, in an emergency, with a broken drag-link or a broken brake-rod?

MR. MYERS:—With a broken drag-link the car will tend to go straight ahead and good brakes will stop it.

MR. HORINE:—The Curtis Co. solved the problem of motorcycle wheel-wabble 15 years ago. In ordinary construction the center-line of the pivot of the member on the top of the fork, that corresponds to the king-bolt on a wagon, does not intersect the axle of the wheel but comes somewhat behind it, crosses the vertical center-line of the wheel and intersects the road at a point in front of that of tire contact. The Curtis arrangement was to extend that center-line so that it intersected the axle, and to use perfectly straight forks, a construction for motorcycles that is almost universal practice on automobiles today.

O. A. MALYCHEVITCH:—Does Mr. Chase consider that an equal number of turns of the steering-wheel ought to be required to steer to the right and to the left; say to have two turns of the steering-wheel to steer to the

right and two turns to steer to the left? I have found that this is very seldom true on the chassis. In designing buses, the steering is a very important item. After experimenting and also from the literature[12] I observed that if the drag-link is parallel to the axis of the chassis as at the left of Fig. 28, the angle between the arm connected with the drag-link and that connected to the tie-rod ought to be equal to 90 deg. If the drag-link is inclined to the right or to the left, the angle ought to be correspondingly increased or decreased as shown in the central and right portions of the illustration.

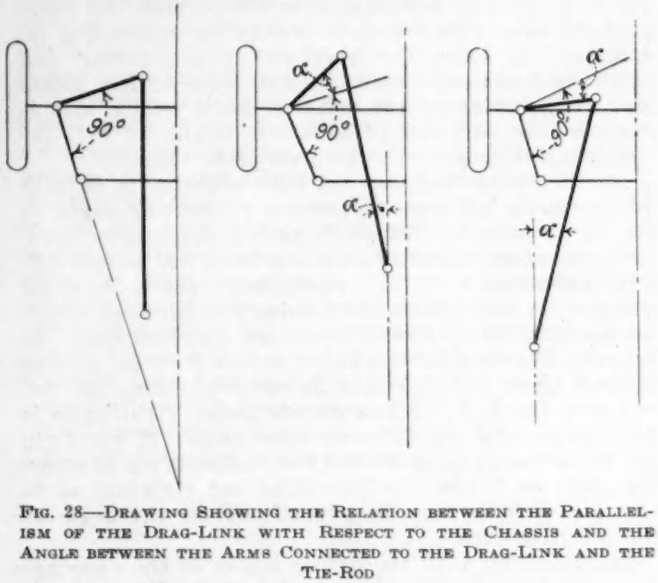


FIG. 28—DRAWING SHOWING THE RELATION BETWEEN THE PARALLELISM OF THE DRAG-LINK WITH RESPECT TO THE CHASSIS AND THE ANGLE BETWEEN THE ARMS CONNECTED TO THE DRAG-LINK AND THE TIE-ROD

Regarding irreversibility, one of the most efficient types of steering-gear is that found on the Schneider omnibus chassis used in Paris and described in *Engineering*.[13] In this form of steering-gear, which is of the screw-and-nut type, the steering shaft that is located near the steering-wheel has a ball-and-socket joint to allow a swinging motion of the screw and the nut on the other end of the shaft; the nut of the steering-gear being connected with the steering-lever. The whole arrangement is very simple and efficient and keeps the steering-system from irreversible action when the shocks come on it. It is said that it is a very quiet steering-system, with no wabbling or kick on the hands of the drivers in such traffic as that in Paris.

OTTO M. BURKHARDT:—Quoting Mr. Chase's statement, where he is referring to the center-point steering layout, we note,

> (1) Road shocks in the plane of the wheel have a minimum moment about the knuckle-axis and, consequently, are transmitted in a less degree to other parts of the steering mechanism

This statement is susceptible of some further qualifications that have come to my attention lately. With center-point steering, the moment of the forces acting on the wheel is of smaller magnitude but, in spite of this, small-magnitude forces in the case of center-point steering are more readily transmitted to the steering-wheel, unless the forces applied are equal on both wheels, which very rarely happens. If one wheel is subjected to a shock, it is not resisted by the other wheel in the same manner as in the conventional American type of steering. The greater the distance from the point of contact between the tire and the road to the axis of the king-pin, the more readily does the wheel act as a shock-absorber.

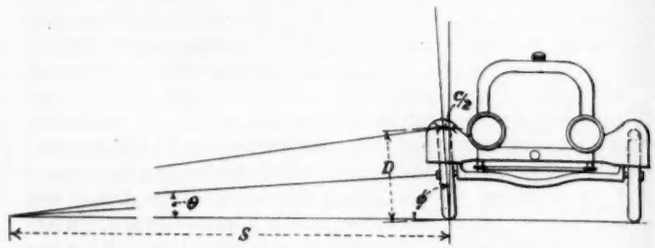


FIG. 29—DIAGRAM SHOWING HOW A CAMBERED WHEEL RESEMBLES THE BASE OF A CONE LYING ON ITS SIDE

With regard to determining the foregather, this is very carefully analyzed by J. C. Sproull.[14] Quoting from Mr. Sproull's paper and referring to Fig. 29, it may be considered that the wheel forms the base of a cone lying upon its side as shown. The natural path of such a wheel, when it rolls on a plane surface, is the circumference of a circle described about the apex of the cone as assembled. Obviously, unless the front wheels have gather, there will be a tendency for them to separate, when they roll on a plane surface.

From Fig. 29 we read the following equation:

$$\cos \Phi = \sin \Theta = C/2D$$

From the figure it is further evident that

$$\sin \Theta = D/2S$$

Hence

$$S = D/2 \sin \Theta$$

From Fig. 30 we observe that the area of the tire in contact with the ground is of the length L. The cone distance, as previously mentioned, is S. We read from Fig. 30

$$\sin \alpha = L/2S$$

The proper amount of foregather is obtained by making $pq = qr$. From the geometry of the figure it follows that

$$qr = (L/2) \tan \beta = S\,[(1/\cos \alpha) - 1]$$

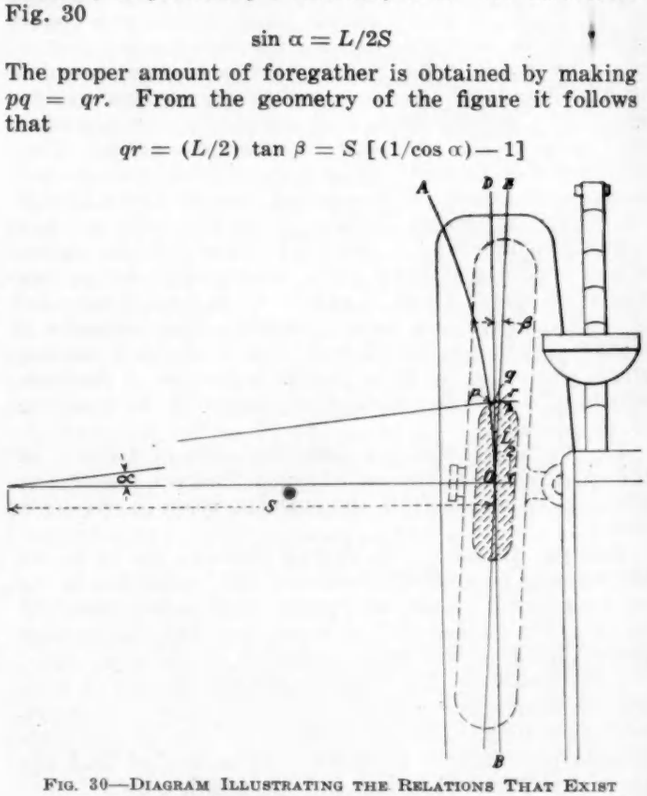


FIG. 30—DIAGRAM ILLUSTRATING THE RELATIONS THAT EXIST BETWEEN CAMBER AND GATHER

[12] See Etude de Direction, by P. Ravigneaux; published in *La Technique Automobile*, 1914 and 1920.
[13] See *Engineering*, April 14, 1916, p. 343.
[14] See THE JOURNAL, July, 1922, p. 91.

In the article mentioned, values have been substituted and tables worked out for practical values of the wheel diameter and the transverse inclination of the steering-pivot.

Mr. Myers mentioned that bearing loads are very important in steering. I agree that the loading of the king-pin bearings has considerable influence on the ease of steering. Figs. 1 and 3 of the paper illustrate three designs that perhaps are representative. Let us consider Fig. 1. We have there a steering-knuckle in which the steering-pivot is overhanging; that is, in case of side-sway, the upper bearing will have to resist a force that is the sum of the side-sway and its reaction, as we have it in the bevel pinions where we have an overhang. Fig. 3 represents a condition of bearings that are fairly symmetrically mounted, what we could call straddle-mounted. There the side-sway would only be one-half on each bearing.

I have not yet seen any clear emphasis in the literature as to what the bearing loads really are. The matter is at first somewhat deceiving. In the case of the Crane design, which is a late job, we find the bearing mounted directly in the knee of an angle. It seems that this bearing gets a tremendous load, but it does not.

A. J. SCAIFE:—Mr. Chase emphasized the desirability of using the ball-and-socket joint in the cross-steering rod-end. We used this construction several years ago but abandoned it because the ball did not retain its spherical shape; it became flattened or oval in shape. When the lost-motion is taken-up on the ball-and-socket joint, the steering becomes cramped when turning to the right or to the left; we therefore abandoned this construction and substituted that of the pin and yoke.

We have had considerable experience in the use of an anti-friction bearing on the top of steering-knuckles to carry the load. It is true that either the ball or the roller bearing will pit, but under the pitted condition these bearings have less friction and turn more easily than the large plain-bearing surfaces, as the friction in the steering-knuckle is in proportion to the bearing surfaces. A continuous ring in the ball race instead of balls has been tried recently with success. It reduces the friction and decreases the wear.

I had a case where the wheel-wabble was extreme. The steering mechanism was loose in every joint; in fact, the lost-motion of the steering-wheel was so great that you could turn the wheel about one-half revolution. Without tightening the joints or taking out the lost-motion, it was possible to eliminate the wabble of the front wheels by inserting a taper wedge between the spring-seat and the springs on the front axle, changing the angle of the caster. This proved to my mind that the caster has considerable to do with the wabble.

It is necessary that the drag-link be designed properly, with suitable relation to the front spring-eye and the steering-arm. We believe it is not possible to eliminate wheel-wabble by simply maintaining tight connections on the steering-gear.

L. H. POMEROY:—Many speakers have discussed the difficulties arising from the relative movement of the drag-link and the front spring. Why not shackle the front spring at its forward end so that the steering-arm will be subject to the influence of two links moving with sympathetic curvatures and not the reverse as is usually the case? This practice has been used by De Dion in France for years and by the Fifth Avenue Coach Co. and seems so obviously right as to make it difficult to understand why the practice is not universal.

Another matter worthy of far more attention than it usually gets is the point where the steering-arms produced intersect the longitudinal axis of the car. On the 1913 Vauxhall cars this point was located a distance about 56 per cent of the wheelbase, measured from the front axle toward the rear. While the steering was delightfully free, the experience at the Front with these cars was that when in deep mud the driver had to descend from his seat to find in which direction the wheels were locked. In a word the steering-gear itself had no powers of recovery or sense of direction. Lengthening the distance of the intersection of the steering-arms and the longitudinal axis from 56 to about 65 per cent made all the difference. While steering was not so free as before, the natural sense of direction was vastly improved.

Remarks have been made on the inadequacy of ball joints. Unfortunately these are essential with inclined pivots. The important thing seems to be that of keeping mud and water out of the joint. If this is done no trouble should arise; otherwise trouble will arise irrespective of whether ball or pin joints are used.

The subject seems to boil down to the fact that wheel-wabble can be caused by half a dozen different factors but needs the presence of three or more of them, thus giving about 20 distinct and accurate diagnoses. I remember a client who many years ago insisted upon heavy detachable rims as well as detachable wheels. During the very first run on the car when everything was tight wheel-wabble developed to such an extent that traffic was stopped to allow him to proceed. Investigation showed that releasing the steering-wheel when the wabble started restored matters to normal, the eventual complete cure being obtained by discarding the heavy rims.

A. D. T. LIBBY:—Mr. Chase has disavowed any originality in connection with his paper. It seems to me that he should have listed the various authors whom he quoted, so that we could look to them for future discussions. The subject of wheel-wabble is very important, and we should have more papers dealing with it.

DR. H. C. DICKINSON:—I should like to say a few words from the point of view of fundamental mechanics as distinct from that of practical steering-system design. This refers only to wheel-wabble of the kind that has a definite period of oscillation and not to motions that represent merely reactions of road roughness on the steering mechanism. This kind of wabble occurs on smooth as well as on rough roads and, being a periodic oscillation, certain underlying principles must apply to it, whatever the detailed forces involved may be.

First, for a system to continue to vibrate, it must have a free period of its own; in other words, it must follow somewhat the same laws as the pendulum follows; it must have a tendency to return to its normal position when forced out of that position. That is the first requisite for wabble to occur. The second essential is that, when the system is forced out of its normal position, there be some actuating force involved, other than its normal force of restitution, that maintains the periodic motion. The third essential is that the total friction, or damping, be no greater than the total force that tends to maintain the motion.

Scores of different forces may be involved; the system as a whole is complicated. It might simplify matters to consider the relation that the three essentials bear to the problem in hand. First, I think I am right in saying that steering-wheels could not wabble if the center of rotation of the wheel passed through the center of support on the road; that is, if there were no castering action whatever, wheel-wabble could not occur. Another condition under which it cannot occur is when the steer-

ing-gear is irreversible. If there is no lost motion, a completely irreversible wheel cannot wabble. A third thing that could absolutely prevent wabble is having the resistance to motion, that is, the friction in the steering-gear, greater than any force applied tending to maintain the vibration of the system. Those three conditions would absolutely prevent wabble. Probably none of them is desirable in a steering system; therefore, perhaps wabble cannot be prevented in that way.

Of the possible causes that have been discussed, most of them are matters of degree rather than of kind; that is, a change in the amount of caster action, a change in the angle of the wheel and a change in the amount of friction all tend to increase or decrease the tendency to wabble. None of them eliminates it. If there is a force tending to produce wabble and it is only just sufficient to maintain the wabble, when we increase the friction or decrease the caster action, the particular steering-system will cease to wabble.

In a steering-system that has caster action and is not irreversible, certain forces are always involved that tend to maintain the wabbling motion; at least, there may be such forces. One of them has been referred to, namely, the tendency of the driver to hold the steering-wheel very rigidly. Under such a condition, a force is introduced that may maintain a periodic oscillation. If that occurs, the wheels can continue to wabble, provided always that the friction is not greater than the force applied. Wabble from this cause will stop as soon as the driver releases the steering-wheel.

A second source of forces that can maintain wabble is the moment produced about the steering center by the friction of the wheel on the ground when it is turned away from the normal position. The forces set up in this way may be of considerable magnitude.

A third obvious source of energy that might maintain wheel-wabble is the reaction produced when a car begins to "shimmy" or oscillate from side. The abnormal periodic side-sway of the car itself under this condition introduces a turning-moment about the steering-knuckle pin that, if it happens to fall at a certain period, can maintain wabble of the wheels. It may be of value in studying this problem to hark back occasionally to the underlying principles that must govern it and check-up how the actual forces involved are related to the underlying principles of simple harmonic vibration.

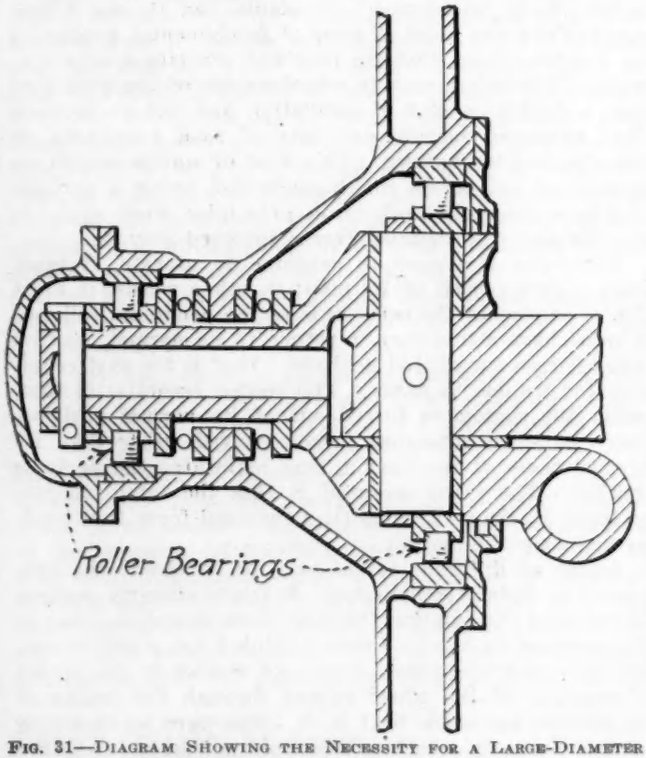


FIG. 31—DIAGRAM SHOWING THE NECESSITY FOR A LARGE-DIAMETER INNER BALL OR ROLLER BEARING

DAVID FERGUSON:—Mr. Chase's paper and the discussion should result in clearing-up many points about which there is much misunderstanding at present. There is no doubt of the desirability of the so-called center-point steering, and it is generally conceded that such types as the old Marmon and the suggested designs of W. J. P. Moore are too expensive and bulky; many such designs have been in production and abandoned. A. L. Riker had a very similar design in his electric cars built over 26 years ago. The Leyland Co., in England, used a design almost identical with Mr. Moore's suggestion on all their motor trucks up to about 8 years ago, when it adopted the more conventional design.

It is apparent from Fig. 31 what a large-diameter inner roller or ball-bearing is necessary. Mr. Moore's sketches are apparently diagrammatic, it being impossible to assemble the stub axles on the spherical ends of the I-beam axle as shown. The length of the bearing indicated on the ends of the I-beam axle are much too short for long life and freedom from wear. When these are made adequate to resist the load due to the front wheel striking a rut or a curb sideways, the size of the large ball-bearing will be excessive.

These designs are all shown with a horizontal stub-axle. This looks very bad in practice, due to the roads being made with considerable camber for drainage and it being desired to have the wheels run in a plane radial to this curved surface, or due to the early adoption of the artillery wheel with the rather pronounced dish that used to be given to the spokes so as to make the wheels stronger sideways, the lower spokes being kept vertical by sloping the stub axles. It has become the universal practice to slope the front stub-axles from 1½ to 3 deg., and a car with horizontal stub-axles looks as though the front axle had sagged and allowed the wheels to assume a knock-kneed position. This would actually be so, as the I-beam axle will deflect considerably on account of the load on it. Any play in the vertical pivot-pins or the wheel bearings will give an additional slope to the wheels; so, it is desirable to give almost 1 deg. of slope to the stub-axles to make the wheels run in a vertical position on a flat cross-sectioned road and they should have at least 1 deg. additional slope to compensate for the usual camber on roads. Some manufacturers make the rear axle with sloping wheels also, although this is very exceptional, because of the expense and complication involved. But the front stub-axles can be made to slope just as easily as they can be made horizontal, when of conventional design, and a little extra slope gives a very rakish appearance to the car and has the distinct advantage of lessening the distance from the center of the tire to the pivot-pins, besides giving a considerable increase to the steering lock with standard tread at the tire contact with the road.

The inclined knuckle-pin shown in Fig. 10 of the paper is a very simple and inexpensive means of accomplishing so-called center-pivot steering, the only disadvantage being the alleged tendency for wheel-wabble, and the raising of the car when the front wheels are turned as in Fig. 32. By drawing these diagrams to scale it will be seen that, when the front wheels are turned through an angle of 90 deg., the I-beam axle being assumed to remain

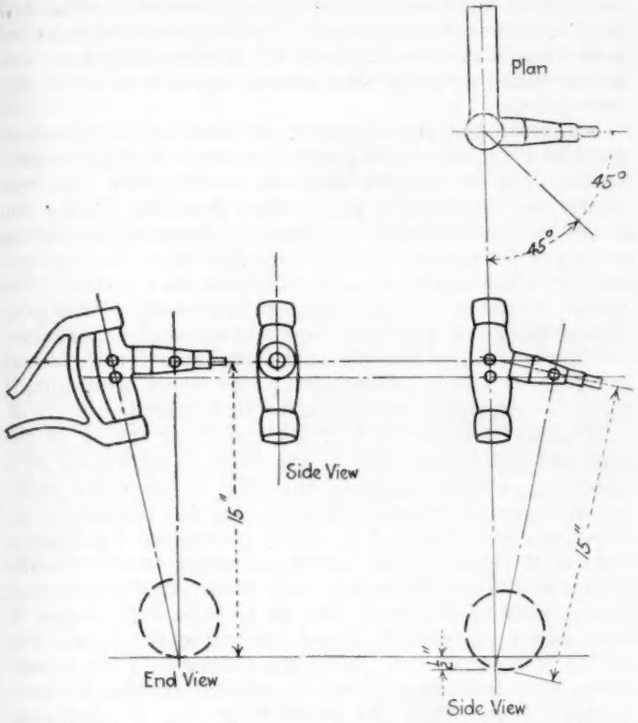


FIG. 32—DIAGRAM ILLUSTRATING HOW A CAR IS RAISED SLIGHTLY WHEN THE FRONT WHEELS ARE TURNED

at the same height from the ground, the wheels will sink into the ground ½ in. Of course, it is impossible in practice to turn the wheels through a greater angle than about 45 deg., in which case both front wheels would sink into the ground ¼ in. Since the ground is fixed, the whole front of the car, including axles and wheels, will be raised ¼ in. This must make steering more difficult than with vertical pivot-pins and center-point steering, though it will have the advantage of a greater self-righting tendency.

Were it not for the fact that motor-car companies feel they have to conform to public taste in regard to wheels, some demanding wood, some wire and some disc wheels, it would be very simple to obtain center-point steering with vertical pivots by adopting single-plate disc-wheels, though I believe a well-made wood wheel is the best type. On the other hand, a steel-disc wheel is preferable to a poorly made wood wheel. One prominent builder has already pinned his faith to disc wheels by adopting a design that will not permit of using wood or wire wheels, without changing the tread. Fig. 33 illustrates this design, the dotted disc-wheel and tire showing it as now being manufactured and the full-line disc-wheel and tire indicates a proposed means to give center-pivot steering with vertical pivot-pins. Of course, the hub flange should be moved farther out to give increased dish to the disc wheel.

There are two objections to this design. It necessitates an I-beam axle 3 in. longer, retaining the 56-in. tread, giving increased weight, and it increases the load on the inner bearing of the wheel. It might be argued that the ease of steering of the present excellent design, in which the projected center-line of the pivot-pin is only 1½ in. away from the center of the tire at the ground, would not be bettered enough in the suggested design to warrant the changes specified. It is possible that this is so, unless front-wheel brakes were to be used, in which case approximate center-point steering is very desirable. The single-plate disc-wheel lends itself to accomplishing this without any great change to conventional designs of steering-pivot axles and hubs.

MR. CHASE:—Mr. Libby expresses the view that I should have listed the various authors from whom information was obtained in preparing the paper. Several are so listed. The bulk of my material was obtained, however, through conversations with various engineers and from letters in answer to a questionnaire that I sent out. In a majority of cases the information secured was not original with the person who furnished it, except perhaps as to certain personal experiences that go to prove a general rule, but is a part of the common knowledge of the subject.

Take the communication that was read by Mr. Myers, for example. In it he made three main points concerning wheel-wabble

(1) Effect of divergent arcs described by the drag-link and the spring
(2) Effect of lost-motion
(3) Effect of unbalanced wheels

Doubtless Mr. Myers has had considerable experience with all of these phenomena, as have many other engineers. All of them are referred to in an article in *Autocar*,[15] which is itself a summary of several earlier articles on wabble in the same publication. Mr. Clayden

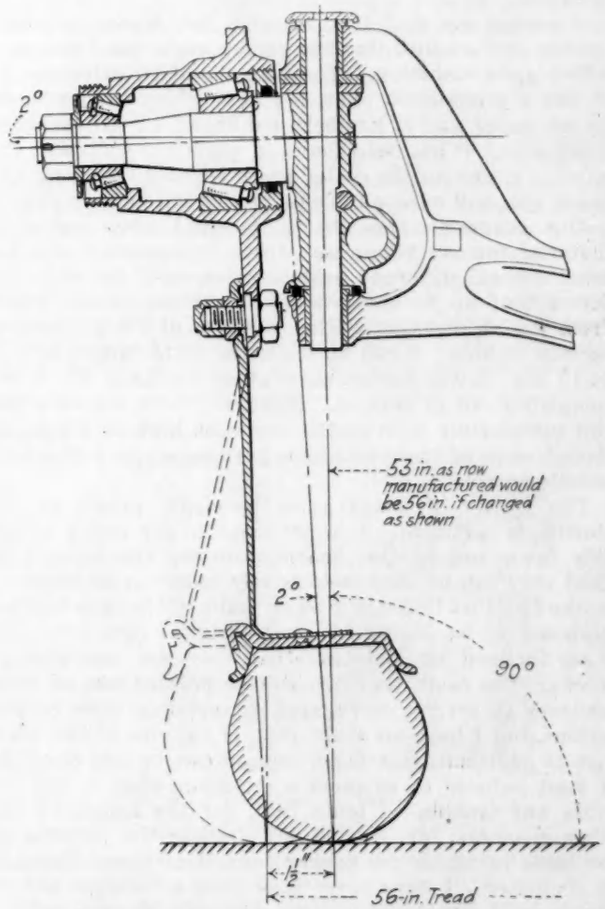


FIG. 33—DRAWING ILLUSTRATING THE STEERING-PIVOT CONSTRUCTION ADOPTED BY ONE AMERICAN AUTOMOBILE COMPANY

The Dotted Lines Show the Disc-Wheel and Tire Arrangement Now Used, While a Proposed Construction To Give Center-Point Steering with Vertical Pivot-Pins and Also Using a Disc-Wheel Is Indicated by the Full Lines

[15] See *Autocar*, July 7, 1922, p. 50.

in an article cited in my paper and discussed by Mr. Myers refers to unbalanced wheels as a cause of wabble and the same thing is referred to in *Motor Age*.[16] References to the effect of drag-link and spring-arc divergence were made in *Horseless Age* nearly 15 years ago and many later references can be found in *Automotive Industries* to this and to the effect of lost-motion in accentuating wabble.

In short, these are matters of common knowledge among engineers familiar with the art, so that no author who attempted anything approaching a thorough survey of the subject could possibly overlook them in preparing a paper of this kind. It probably would require months of study to find who first discovered the numerous facts that I have assembled. Hence, I have not attempted to give the sources of my information except in a few cases where I was fortunate enough to find a printed article that dealt at some length with a particular phase of the general subject. In numerous cases the information on one topic came from several sources and in others I have simply put isolated facts together and drawn my own conclusions, as would any engineer under similar circumstances.

Among those who furnished data on the various subjects treated in the paper were President B. B. Bachman, Dr. H. C. Dickinson, H. M. Crane, J. G. Vincent, A. L. Clayden, C. T. Myers and George P. Dorris. Some of the communications I had were verbal and others were written.

I cannot say that I agree with Mr. Myers in what I gather is his belief that the caster angle has little or no effect upon wabbling. There is abundant evidence that it has a pronounced effect. I have given such evidence in my paper and it has been confirmed in the foregoing discussion. It has been found in numerous instances that slightly changing the caster angle without changing anything else will cure wabble or render it inappreciable.

One communication that I received when gathering material for my paper was from an engineer who had tried several different caster-angles with his car. He found that up to about 3 deg. there was little trouble from wabble, but that angles in excess of 3 deg. produced serious wabble. When he made the caster angle as high as 10 deg., it was impossible to steer the car at all; it was completely out of control. However, there are cars that run successfully with caster angles as high as 6 deg., although some of these cars have been known to suffer from wabble trouble.

The matter of anti-friction bearings, raised by Mr. Horine, is pertinent. I do not mean to say that I invariably favor anti-friction bearings on the knuckle-spindle. That they can be used successfully seems to be indicated by the fact that they are used on many of the cars that are supposed to be among the best-designed cars produced. I am inclined to doubt whether they are desirable on trucks. The fault, that Mr. Horine pointed out, of their tendency to become corrugated, is certainly more or less serious, but I have no doubt that, if the size of the bearings is sufficient, this disadvantage can be overcome, or at least reduced to so small a minimum that it will not cause any trouble. I trust that, for the benefit of the other members, Mr. Horine will disclose the formula on the basis of which the proper amount of foregather can be computed. I have never seen such a formula and, if one exists, I would like to know where it can be found.

I am not familiar with the steering-system used on the Schneider buses, and so cannot discuss the point raised in that connection. I realize, however, that the angular position of the tie-rod arms has an important effect and have so indicated in my paper. The angle should be varied according to the wheelbase, as Mr. Horine indicates. The points brought out by Mr. Pomeroy are of interest in this connection.

The matter of the layout of the drag-link is a geometrical problem, and there is no doubt that there are a number of different layouts that are satisfactory. The best is the one that results in the least deviation of the two arcs described respectively about the center of the spring pivot and the center of the ball on the end of the steering-arm with the drag-link center-distance as a radius. The design in which the steering-gear is forward of the axle, as shown in Fig. 15 of the paper, is an excellent arrangement, especially when the space available for the steering-gear is small. Considering the short drag-link, I think the arrangement can hardly be bettered.

Whether it is better to pivot the front spring at the rear and put the shackle at the front is something of a question. I have no doubt that this is desirable under certain circumstances. One of the latest designs of American car that is not yet in production has such a layout. I think that it would be better to shackle the spring at the front end but that when the steering-gear arm is back of the front axle, as it is in Fig. 15 and in some other designs, it would be better to shackle the spring at its rear end. Like Mr. Pomeroy, I am unable to say why front springs are so seldom shackled at their forward ends, when the position of the steering-gear lever is, in a great majority of cases, well to the rear of the axle.

The point brought up by Mr. Burkhardt in respect to the lack of damping tendency of the off wheel in a car with transversely raked pivots arranged to give center-point steering is well taken. A center-point layout is said by some to make the steering easier but, as Mr. Burkhardt says, when one wheel starts to wabble with this construction the other wheel does not offer a counteracting moment, tending to prevent wabble as it does when the pivot is off-center. Whether center-point steering actually is more easily controlled than the other type, I am unable to say.

The point made by Mr. Horine to the effect that with the center-point layout the tire must be twisted about a central point as against rolling it about a central point, when there is an offset knuckle, is worth consideration. There is, however, in either case a considerable twisting action on the tire and I doubt whether there is a noticeable difference when the vehicle is in motion. Some cars with center-point steering certainly do have wonderfully free steering action when they are stationary.

Mr. Scaife raises the point that the ball of a ball-and-socket joint wears out-of-true. That does occur but if particular attention is paid to the lubrication such wear can be minimized. Furthermore, I do not see that it should be any more difficult to replace a worn ball than to replace a worn pin or the bushings when a yoke construction is employed. With the spring-backed socket-type, the play of course is continually taken-up; hence the ball type has the distinct advantage that it tends to eliminate rattle. As Mr. Pomeroy pointed out, it is absolutely necessary to use the ball type when the transversely raked pivot is employed.

The matter of the layout of the tie-rod arms, raised by Mr. Pomeroy, is interesting; it is a geometrical problem; several papers have been written on the subject, one or two of which are referred to in the paper. The general impression is that the best layout is the one in which the extension of the center-lines meet at the center of the

[16] See *Motor Age*, Nov. 16, 1922, p. 22.

rear axle. Some state that a little better layout is obtained by bringing that point somewhat forward of the rear-axle, but I was not aware that any one brought it as far forward as Mr. Pomeroy indicates that he has found to be desirable.

Dr. Dickinson said, "If there were no castering action whatever, wheel-wabble could not occur. . . . Another condition under which it cannot occur is when the steering gear is irreversible." I think he is correct in-so-far as he refers to certain periodic tendencies to wabble. It is undoubtedly true, however, that it is possible to produce wabble by having a faulty drag-link layout, or by having a wheel that is badly out-of-balance, even with castering and with an irreversible gear.

MR. MYERS:—I do not want it understod that I believe the castering action has no effect on the wheel-wabble. In my experience it has been possible to use the castering action up to about 2 deg., varying anywhere from 1½ to 2½ deg., without any bad effects, so long as the other points are taken care of.

SEVENTH SEMI-ANNUAL GASOLINE SURVEY

FOR a number of years the Bureau of Mines has conducted semi-annual surveys to determine the changes in motor gasoline being sold in the United States. The present survey shows that the tendency toward an increase in volatility that was noted 6 months ago is still present, and that the seasonal variation from summer to winter grades is apparently slowly decreasing. A careful review of the data obtained in the previous surveys, beginning with that of 1917, shows that there is a tendency toward a greater uniformity in the character of the gasoline marketed in the United States, as shown by the figures in Table 1, which were obtained by averaging the end-points of the least volatile and the most volatile samples of gasoline. For example, of the 850 samples analyzed in 1919, the 10 per cent of the samples having the highest end-points and the 10 per cent having the lowest end-points were grouped, and the end-points of each group averaged. These averages are represented in the table as the "Maximum 10 Per Cent" and the "Minimum 10 Per Cent" respectively. The same process was used on the other surveys. An examination of the "Differences" shows that the range of "end-points" in each survey is less than in the previous one, indicating a tendency toward uniformity.

TABLE 1—RANGE OF END-POINTS IN EACH GASOLINE SURVEY

Date	Maximum 10 Per Cent, Deg. Fahr.	Minimum 10 Per Cent, Deg. Fahr.	Differences, Deg. Fahr.
April, 1917	449	334	115
April, 1919	472	363	109
January, 1920	482	377	105
July, 1920	502	406	96
January, 1921	467	382	85
July, 1921	473	398	75
January, 1922	461	397	64
July, 1922	461	401	60
January, 1923	451	397	54

In the present survey, taking the cities individually, there are some distinct changes noted. In comparison with January, 1922, the average for the City of Washington shows an increase of 20 deg. in the initial boiling point and a decrease of 12 deg. in the 90 per cent point. The averages for Pittsburgh, Chicago and St. Louis each show consistent drops throughout the distillation range with the exception of the initial boiling point, which was increased slightly. On the other hand, the averages for Salt Lake City and San Francisco indicate, on the whole, a decrease in volatility. The average 90 per cent point and the end-point of the San Francisco samples each rose 11 deg., while the same points of the Salt Lake City samples rose 8 and 2 deg. respectively. In the distillation of the samples from Pittsburgh and St. Louis it was found impossible to recover even 90 per cent of some samples when using a mixture of ice and water in the condenser bath according to the standard method of distillation. This would indicate that these samples contain an excess of low-boiling fractions, which is probably due to an admixture of an excess of natural-gas gasoline.

A distillation curve was plotted representing the grand average of all the analyses for the January, 1923, survey, together with one that represents a motor gasoline meeting Federal specifications. The average survey curve falls well below that representing Federal specifications, but it conforms very closely in shape to the specification curve.

In the present survey the samples were tested in accordance with the methods given in Bureau of Mines Technical Paper 214, entitled Motor Gasoline; Properties, Laboratory Methods of Testing and Practical Specifications, by E. W. Dean. The actual specific gravity at 60 deg. fahr., the corresponding degrees according to the American Petroleum Institute scale, the initial boiling point or first drop, the 20, 50 and 90 per cent points, the end-point, the average boiling point and the per cent recovered in the receiver were determined. The average figures for each city are shown in Table 2.—From a report prepared by N. F. LeJeune and L. G. Marsh, of the Bureau of Mines.

TABLE 2—AVERAGE RESULTS OF THE JANUARY, 1923, MOTOR-GASOLINE SURVEY

District	Specific Gravity	American Petroleum Institute, Degrees	Temperature, Deg. Fahr. First Drop	20 Per Cent	50 Per Cent	90 Per Cent	End-Point	Average Boiling Point	Amount Recovered, Per Cent
New York City	0.739	60.0	101	201	270	368	420	267	96.3
City of Washington	0.758	55.3	118	202	261	368	424	267	96.8
Pittsburgh	0.729	63.0	95	171	244	382	423	249	92.8
Chicago	0.745	58.4	107	202	268	379	433	271	96.5
New Orleans, La.	0.743	58.9	117	213	280	376	428	278	96.9
St. Louis	0.736	60.8	103	196	269	382	433	268	95.4
Bartlesville, Okla.	0.742	59.3	109	205	273	381	440	274	96.4
Denver, Colo.	0.744	58.6	109	205	273	369	419	270	96.5
Salt Lake City, Utah	0.742	59.4	98	199	265	370	414	264	95.7
San Francisco	0.759	54.9	113	207	265	370	432	269	97.3
Average	0.744	58.8	107	201	267	375	427	268	96.0

[1] Failed to meet the specifications for Federal purchases adopted Feb. 3, 1922, and revised Oct. 31, 1922.

SOCIETY MEETINGS

GENERAL-PURPOSE FARM TRACTORS

Will Feature National Tractor Meeting in Chicago This Month

Arrangements have been made definitely to hold a national Tractor Meeting of the Society in Chicago at the Auditorium Hotel on Thursday, April 19. This date just precedes an important meeting of the Farm Equipment Manufacturers Association. Two engineering sessions will be held, one in the morning and the other in the afternoon. The morning session will start at 10 o'clock and the afternoon session at 2.30 p. m. An informal Tractor Luncheon has been arranged during the noon period between these two meetings, this forming the social feature of the meeting.

Prof. O. W. Sjogren of the University of Nebraska faculty will read a very important paper in the morning meeting. This paper will set down constructive criticism of an engineering character that has come to light as a result of the extensive tractor tests conducted at the University of Nebraska for the State. These tests are widely known and respected for the unprejudiced manner in which the ability of various types and makes of farm tractor is determined. Professor Sjogren has been in charge of this tractor testing work and his paper is prepared with an altruistic motive in mind; he wishes to place before the industry the outstanding engineering faults of the tractors that he has tested for the purpose of encouraging engineering development and a greater perfection of the tractor as a farm implement.

The afternoon meeting will be addressed by C. M. Eason. Mr. Eason is well known in the tractor industry, having been connected with it for a number of years, serving at one time as vice-president of the Samson Tractor Co. Mr. Eason is an enthusiastic advocate of the general-purpose type of farm tractor capable of doing all of the work now done on the farm by horses. He will record some of the progress that has been made in the development of this type of machine and will illustrate his talk with numerous photographs. As a part of his paper, Mr. Eason has collected the opinions and experiences of a large number of representative tractor engineers and these will form an important contribution to the discussion.

Tickets for the luncheon may be ordered from the New York City office using the blanks soon to be forwarded to the members with a special issue of the *Meetings Bulletin*. The tickets are priced at $2 per plate. It is intended that the luncheon gathering will be addressed by an eminent agriculturist whose views on farm economics will form both an interesting and educational diversion from the engineering talks of the morning and the afternoon. It is expected that the Tractor Meeting will be attended by a representative group of tractor engineers because of its location in the center of the tractor building territory and its being scheduled just previous to another important activity of the tractor industry.

MOTOR TRANSPORT APRIL FEATURE

National Meeting in Cleveland Devoted to Truck, Bus and Taxi Operation

Operation experience in three important fields of automotive transportation will be featured in the National meeting of the Society at Cleveland, April 26 to 28. In some respects this meeting is a departure from the lines of activity followed by the Society in the past; we are to enter the field of operation in an active way. Practically all of the discussion and the papers will be built around problems of operation; some time, of course, will be devoted to maintenance as well. The operation of the motor truck, motorbus and the taxicab will be touched upon; there are important and valuable papers on each of these three means of commercial transportation. A glance at the program on the opposite page reveals the importance of the several papers and in each instance, the author's connection indicates that he is able to speak with authority on operation problems.

The combination of valuable papers, a central meeting location, reduced railroad fares, and the opportunity to meet representative men engaged in the operation of motor-vehicle fleets, should prove sufficiently attractive to lead every executive and engineer to attend the Automotive Transportation Meeting, April 26 to 28, in Cleveland. All of the meetings and the Transportation Dinner will be held at the Hotel Winton. Reservations for rooms may be made by addressing the hotel authorities direct. Garage facilities are ample and reservations may also be made for the storage of your car if you decide to drive to Cleveland.

At the time of writing this announcement, the scheduling of the several papers has not been determined upon; this is largely because of the fact that additional contributions are expected. The definite schedule of meeting periods and presentations will reach all of the members of the Society through a special issue of the *Meetings Bulletin* about April 17.

The large amount of material available on motor-truck, motorbus and taxicab operation made it necessary to eliminate consideration of the motor rail-car from the program of this Cleveland Meeting. Each of the other mediums of commercial automotive transportation will receive full consideration and discussion. It is planned to have a representative engineer of a vehicle manufacturing plant assigned to the discussion of each of the papers. The names of these discussers will be announced in the special *Meetings Bulletin* referred to above.

The technical sessions will be held during the morning and afternoon of April 26 and 27. The Automotive Transportation Dinner will be held at the Hotel Winton on Thursday evening, April 26. It is hoped to secure an outstanding public official who is interested in the extension of automotive transportation to speak at the dinner. A card for the making of dinner reservations will be forwarded to the members in the near future. Visits of inspection will be made to the factories of the White Motor Co. and the Nela Park Laboratories of the National Electric Lamp Association. It is probable that these visits will be arranged on Saturday morning, April 28.

The Society intends to give a large amount of publicity to this meeting among motor-truck operators, traffic and engineering departments of the railroads, and the electric traction companies. This will be done for the specific purpose of bringing to the meeting a large and representative group of commercial motor-vehicle users so that they may meet and exchange views with the engineers and constructors of this equipment. A study of the present status of automotive transportation evidences great need for such a cooperative gathering. Those directing the arrangements for the meeting have already noticed a widespread interest in it among the users; it is to be hoped that an equally great enthusiasm and interest will be shown by those in the industry who are concerned with the production of the motor-vehicle equipment.

Mark the date of the Automotive Transportation Meeting on your calendar at once; make arrangements to attend the meeting in person and bring with you all those members

of your staff who should and must become more closely allied with the purchasers and the operators of commercial motor vehicles made by your organization.

PAINT AND VARNISH TROUBLES

Form Subject of Instructive and Largely Attended Detroit Section Meeting

Painting and varnish troubles were discussed in a very comprehensive manner at the meeting of the Detroit Section of the Society on March 2 which attracted over 265 members and guests. L. Valentine Pulsifer, chief chemist of Valentine & Co., was the speaker of the evening. He presented the salient points taken from his two previous addresses before national body engineering meetings of the Society. These papers appeared in THE JOURNAL for January, 1922 and January, 1923. The speaker particularly stressed simple methods of testing varnishes that enable one to determine their durability, elasticity and other important qualities.

An innovation was tried at this meeting of the Detroit Section. Cards were passed through the audience on which questions were written by those in attendance; the questions were collected, then read by the chairman in rapid-fire fashion and answered by Mr. Pulsifer. These questions and answers formed at least as valuable a part of the meeting as the paper itself. Appreciating that the information given in the answers was timely and of great interest to those in the production end of the industry, these were edited promptly by Mr. Pulsifer and will be found on p. 335 of this issue of THE JOURNAL.

The next meeting of the Detroit Section will be held on April 6 in the General Motors Building starting at 8 o'clock. The subject of the meeting will be Gear Grinding. Glenn Muffly will read the paper of the evening which will be descriptive of one type of gear-grinding machine and he will also include a discussion of some peculiarities of the involute form of gear tooth. Mr. Muffly's talk will be followed by a period for written questions and for open discussion. The meeting will be preceded by the customary informal dinner at 6.30 p. m., which is always a feature of Detroit Section meetings, there being 140 seated at the March dinner.

MINNEAPOLIS DISCUSSES AIRPLANES

The Minneapolis Section had a varied program at its meeting on March 7. The Modern Type of Airplane formed the topic of a paper by Charles Boehnlein of the engineering faculty of the University of Minnesota. Mr. Boehnlein's paper described some of the airplanes competing in the Pulitzer races at Detroit and the author showed slides reproduced from photographs of the competing planes that he had taken at Selfridge Field. J. D. Mooney, engineer of the Auto Engine Works of St. Paul, read a paper on Airplane Engines in Motorboat Service. Mr. Mooney compared the characteristics of the two types of engines and showed the similar and dissimilar conditions of operation in the two classes of service. Dean Leland of the University of Minnesota addressed the Section briefly on the advantage of local engineering meetings.

The two papers elicited active discussion in which A. W. Scarratt, A. F. Moyer, J. W. Wagner, Victor Gauvreau, A. H. Bates and others were prominent.

AUTOMOBILE VALUES INCREASED

Schipper Believes Public Received This Impression at the Shows

Impressions left by the New York and Chicago Automobile Shows were summarized in a very interesting paper prepared by J. Edward Schipper and read at the meeting of the Buffalo Section on March 16. Unfortunately, Mr. Schipper

AUTOMOTIVE TRANSPORTATION MEETING

Cleveland—April 26-28

TENTATIVE LIST OF SPEAKERS

F. C. HORNER
GENERAL MOTORS CORPORATION

The field for the motor truck in railroad terminal cartage service. Greater load efficiency through scientific cartage control. The unit container. Description of English railway cartage practice. Will include films showing cartage operations of two stations in London.

S. G. THOMPSON—A. J. SCAIFE
WHITE MOTOR CO.

Presentation of a motor-truck company's transportation engineers' recommendations for economic control of truck fleet operation. Covers experience gained from practical operation in many fields.

S. VON AMMON
BUREAU OF STANDARDS

Presentation of results of exhaustive tests of motor-truck rear-axles of all types, conducted for the Army Motor Transport Corps. Data on relative efficiency of worm and internal-gear types an important part of paper.

MAJOR BRAINERD TAYLOR
MOTOR TRANSPORT CORPS

Recommended methods of motor-truck traffic control based on plan evolved by the Army for use in case of national tie-up of rail transportation. Includes valuable experience of army transport in France.

J. F. MURPHY
COLUMBIA TERMINALS CO.

Describes operations of organization engaged in the transfer of inbound and outbound freight between nine railroad depots in St. Louis. Has developed a system of motor haulage that amounts to the operation of off-track railroad facilities through congested industrial sections.

C. D. EMMONS
UNITED RAILWAYS & ELECTRIC CO. OF BALTIMORE

Mr. Emmons is president of the American Electric Railway Association and actively interested in the operation of street cars, motor buses and trackless trolleys. He has spent several months abroad studying urban transportation in the large Continental cities.

PAUL H. GEYSER
YELLOW CAB MFG. CO.

Mr. Geyser has been connected with the development of taxicab transportation for many years. He will present his recommendations on systems of taxicab operation and maintenance. Design requirements for taxicab service will be outlined.

HAROLD B. WESS
R. H. MACY & CO.

Mr. Wess is chairman of the Retail Merchants Delivery Association, an organization that has been promoting a comprehensive research study of motor-truck operation in the retail delivery field. He will describe some of the results accomplished to date.

was unable to attend and his paper was read by J. C. Talcott. Some of the impressions of the author are abstracted in the following paragraphs.

While improved equipment was probably the outstanding feature of the cars at the Shows, it is only a small part of a big movement that has progressed during the past decade. This movement has been one of greater attention to detail. It is not possible to name a part on which attention to detail has not been more carefully focused than ever before. Quality of cars has improved notably; yet, improved production methods and manufacturing economies have made it possible to produce present-day automobiles and sell them at relatively low prices. Improved machinery and methods have reduced the labor-cost per car by reducing the number of hours of labor required to build it, rather than by reducing wages. The elapsed time from the raw material to the finished car has been greatly reduced, with a proportionate saving in carrying charges or overhead. The strongest impression left by the Shows was this ability of the manufacturer to provide the public with better cars at more reasonable prices. Raw materials are better, methods of manufacture are improved, inspections are more exacting, assembly is more carefully conducted and yet cars can be purchased for about the same money as in the pre-war period. If we had made the same automobile in 1914 as that produced today, it is safe to say that prices would be at least 35 to 50 per cent higher. The war rendered a service to the automotive manufacturing business which cannot be under-estimated. The advances made as a direct result of the war represent a development period which would have extended over a great number of years.

The engineer has realized that a product must be designed not only for performance but also for manufacture. There is greater cooperation between the chief engineer and the production manager; this has resulted in a decreased manufacturing cost. Costs have been further reduced by the introduction of special labor-saving machinery. The high cost of much of this machinery has emphasized the necessity for limiting design changes that would render these expensive machine-tools obsolete and this condition has been responsible for a certain stability in design.

Superior engine performance has been sought and attained in various ways as evidenced by the Show exhibits. Reciprocating weights have been reduced, the crankshafts made more rigid and the crankcases made stiffer; this progress has aimed at the elimination of vibration. Another marked tendency in engine design is the use of longer pistons with increased bearing areas that reduce the unit side-pressure on the cylinder walls. A strong tendency was noted toward the more complete use of the complete-pressure system of lubrication. Increased rigidity in structure is not confined to the engine. In going over the 1923 models one notes how many companies have increased the rigidity of the chassis frame. Coupled with this, a stronger body construction has been adopted by many manufacturers.

Service and maintenance charges have been greatly reduced. This is due to improved materials; rendering adjustments and lubrication easier, so that the owner will give them proper attention; and, units that must be removed for adjustment at comparatively frequent intervals have been especially accessible. The detachable cylinder-head has become almost universal practice.

A very active discussion on methods of machining and fitting crankshaft bearings followed the reading of the paper. Some doubt was expressed by David Fergusson and O. M. Burkhardt about the wearing qualities of crankshaft bearings that were machined to interchangeable limits and fitted in the case and to the crankshaft without any hand-work. R. W. A. Brewer made a plea for lighter construction in passenger vehicles; he felt that the present tendency was to continue the production of automobiles that were too heavy for economical operation.

The next meeting of the Buffalo Section will be held in the rooms of the Buffalo Engineering Society, Hotel Iroquois, on April 13. Motion pictures depicting the construction and operation of electric starting, lighting and ignition systems will be shown, accompanied by a talk by C. F. Bishop.

JORDAN TALKS PAINT PSYCHOLOGY

Cleveland Section Will Visit Paint Factory as Part of April Program

The sales value of clothing a motor car in an attractive coat of paint is respected by most motor-car salesmen. The psychology underlying this sales appeal is an interesting study. E. S. Jordan, president of the Jordan Motor Car Co., through his intimate contact with the motor-buying public, has formed some very interesting opinions and theories on paint psychology. He will present them before the Cleveland Section of the Society on the evening of April 10 at the rooms of the Cleveland Engineering Society in the Hotel Winton. Mr. Jordan's talks are always crowded with good logic on motor-car merchandising and much of this will appeal to the engineer. His inimitable manner of presentation makes his talks attractive from the entertainment as well as the educational standpoint.

As a part of its activity on the paint subject, the Cleveland Section has arranged a visit to the manufacturing plant of the Sherwin-Williams Co. during the afternoon preceding the meeting. This visit takes place on Tuesday afternoon, April 10. Members of the Sherwin-Williams staff will serve as guides and will explain all of the details of paint and varnish manufacture. This provides an unusual opportunity for motor-car engineers, body designers and production men to acquaint themselves with the ingredients used in paint and varnish manufacture as well as the methods of preparing and mixing them.

MORE ENGINEERING NEEDED IN SERVICE

Service Authority Believes Maintenance Work Will Profit as a Result

Making a plea for more engineering in automotive maintenance, H. R. Cobleigh presented a very interesting argument to the Washington Section at its meeting on March 2. The subject of his address was Automotive Maintenance Engineering—A New and Inviting Field. As Secretary of Service of the National Automobile Chamber of Commerce, Mr. Cobleigh has had an opportunity to visit many service establishments and his observations have enabled him to formulate some valuable opinions. The following paragraphs give some of the important points brought out in his talk.

Engineering is doing anything scientifically and efficiently as contrasted with simply doing it. The definition indicates exactly the difference between service as we now know it and what it will become when simplified to the status of maintenance engineering. The execution of work in the repair shop must be studied and ways contrived for performing it as efficiently as in the original construction in the car manufacturing process. If cars were built as inefficiently as they are overhauled they would cost about four times their present price. If they could be overhauled as efficiently as they are built, the work could be done for one-quarter its present cost. While this ideal may not be obtainable, certainly much can be done by concentrating the overhaul work in fewer large shops so that the volume of work handled would justify the installation of labor saving machinery, and processes employed that small shops could not afford. The small shops could confine themselves to minor repairs and adjustments, sending units requiring rebuilding or overhauling to the specialized plants, where this larger work could be done better and quicker at half the cost to the owner, and with an equal profit to the individual shop.

Herein lies a practically untouched field of opportunity in which engineering talent might accomplish a great work along the lines of efficient organization, shop layout and equipment, motion and plan study, special tools and training of operators. Let the engineer begin to study repair shop efficiency and he will find that the average service-station can be 75 per cent properly equipped at a reasonable ex-

Schedule of Sections Meetings

APRIL

4—MINNEAPOLIS SECTION

6—WASHINGTON SECTION—Some Observations on Exhaust-Valves—A. W. S. Herrington

6—DETROIT SECTION—A Process of Gear Grinding and a Discussion of Tooth Forms—Glenn Muffly

10—CLEVELAND SECTION—The Psychology of Paint—E. S. Jordan—Visit to the Sherwin-Williams Plant in the afternoon

13—BUFFALO SECTION—Electricity in the Motor Vehicle—C. F. Bishop

16—DETROIT SECTION—André Citroen of Paris, France—The Future of the Light Car

19—METROPOLITAN SECTION—Engineering Features of Fleet Operation—Edward E. La Schum

20—MID-WEST SECTION—General Design of Electric Trucks and Their Performance in Urban Work—J. G. Carroll

pense. Adequate tool and fixture equipment will minimize hand-work, employing machine-tool operations in its stead. The flat-rate system is an encouragement to efficiency; incentive is placed in the way of the workmen to reduce the time he spends on a job to earn a bonus. Short-cuts are a natural development and result in more profit to the service-station and less expense to the owner.

Education of shop personnel and the rating of mechanics are subjects deserving the engineers' study. There are too many mechanics in the business who are poorly and inadequately trained; they are unable to develop tools that save time and labor. It is important, and in no sense beneath the engineers' dignity, that he become concerned about the training of the personnel in the service-station.

It has been the habit in the past to throw away a car before its useful life was really exhausted. Obsolescence has had more to do with the scrapping of automobiles than their wearing out. Now that designs have become more or less standard, the public will not indulge in this practice. It will require a longer useful life from properly maintained vehicles, and insist on reasonable maintenance expense. Repair charges that exceed the retail value of the repaired article many times will not be tolerated. The public will never receive this ideal service, however, until the engineer applies himself to the problem with as great sincerity as he has already applied himself to the economics of design and production.

The next meeting of the Washington Section will be held on April 6 at the Cosmos Club starting at 8 o'clock. The meeting will be addressed by A. W. S. Herrington, who will present the results of some extensive engine-valve tests, made by the engineering division of the Motor Transport Corps.

TROLLEY-BUSES AND FLEXIBLE VEHICLES

Metropolitan Section Discusses Cooperation of Street Railway and Automotive Engineers

A very interesting and vitally important meeting was held by the Metropolitan Section at the Automobile Club of America on March 15. It was attended by various representatives of interests vitally concerned in highway passenger-transportation, such as the City of New York, the American Electric Railway Association, bankers and rolling-stock producers.

William P. Kennedy opened the discussion by elucidating the salient points of the paper he had prepared for study before the meeting, entitled Trolley-Buses and "Flexible" Vehicles. This paper, which was of a comprehensive nature, was analytical in the broad sense and recalled to the mind of various members the unusually timely and instructive papers that Mr. Kennedy has presented at meetings of the Society in the past, such as those discussed at 1911 sessions, on Administrative Engineering and Salesmanship in the Commercial-Car Field and Standardization Possibilities in the Commercial-Car Field. It was Mr. Kennedy's purpose in this paper to bring to the attention of automotive engineers the current situation in the street-railway field and to point out to what extent factors are undetermined in the common problems of automotive and street-railway engineers. Mr. Kennedy proceeded on the assumption that new business is to be had in the providing of so-called flexible transportation equipment for street-railway lines, citing such elements as sight-seeing and freight handling, of which there are interesting current examples in Europe. Such equipment can utilize present railway systems and still be independent. It is felt that the street-railways must provide transportation of the flexible type, the design of bus in common use today not being satisfactory in this respect. Important phases of the desired vehicle are one-man operation, a low center-of-gravity and use so far as possible of the power the street-railways can now furnish. Trolley-buses can, of course, be provided with auxiliary equipment such as gas-engines or storage- batteries for propulsion when the trolley is not used; the street-railways have expressed a desire for this. Mr. Kennedy said that the trolley-bus has been used successfully in Europe since 1903, freight-lines being operated. He argued in favor of gas-electric transmission in public passenger-service, claiming that it reduces the cost of operation of vehicles of long life, is quiet, decreases general wear-and-tear and saves brakes. He advocated also using trailers with tractors, mentioning with emphasis the necessity for interchangeability of parts and standardization of units.

Among the places in this country where trolley-buses are operated at present are Baltimore; Minneapolis; Los Angeles; and Staten Island, New York. They are being used also in Toronto, and Windsor, Ont., Canada. The motor used, which is the light street-car type, is too heavy. One model of English trolley-bus has a single motor and worm-gear drive. There is in England also a double-deck bus, with motors attached independently to the driving-wheels.

Mr. Kennedy showed some new designs of tractors and semi-trailers with trolley-motor or gas-engine equipment. The tractor is detachable so that the type of body can be changed easily. The steering is through the rear wheels, controlled by the tractor. The trolley motor-coach has capacity for 100 persons.

G. C. Hecker, special engineer of the American Electric Railway Association, said that the time is ripe for cooperation between street-railway and automotive engineers. He referred to the reported cost of 36 cents per bus-mile of the Fifth Avenue Coach Co.; stating that the best comparison is the cost per passenger carried, this being more than 7 cents in the case of the said company and over 5 cents in street-railway operation. Mr. Hecker said that the trackless-trolley-car should be useful in new territory but that the public must understand that it will have to pay more if bus transportation is more expensive. The lean routes affect the total earnings of companies. The street-railways have a heavy load to carry in the way of taxes and other charges.

Incidentally, Mr. Hecker expressed the belief that the business of the street-railways is greater at present than it has ever been before. Requirements in the design of vehicles for public passenger-transportation are maximum standardization, the greatest feasible comfort, rapid loading and unloading, a satisfactory method of collecting fares in one-man operation, and certain safety arrangements to prevent accidents.

R. E. Fielder, chief engineer of the Fifth Avenue Coach Co., said that the gas-electric transmission did not compare favorably with the mechanical transmission in the service of his company during several years of operation, the acceleration of the former being sluggish, the gasoline consumption higher and the weight greater. He feels that the mechanical transmission is now sufficiently quiet and satisfactory. He said that it is being found that gasoline-bus operation is more economical than the conventional street-car operation; that with one-man operation and without undue taxation a cost of 24 cents per bus-mile is possible.

Speaking to the point made by Mr. Kennedy that due to development in a non-competitive field there had been an unjustified feeling of security until a few years ago on the part of the street-railway operators, C. W. Kellogg, of Stone & Webster, Boston, said that the electric railways have had great problems that spurred them as much as competition could have stimulated them, they having been compelled to exert strenuous efforts to improve and reduce the cost of their service. He summed up his remarks by saying that what it is desired the automotive engineer shall produce is a comfortable, low center-of-gravity vehicle.

F. C. Horner pointed out that motorbuses run on the average as much as 50,000 miles per year, at a greater speed than that of the truck, which travels 6000 to 8000 miles per year. He reported from recent personal observation that there is no increase in the use of trolley-buses abroad, some tramway men whom he interviewed having said that these vehicles have most of the objections of the trolley-car and none of the advantages of the bus. He believed that the field for trolley-buses in this country is limited.

C. J. McPherson, of the J. G. Brill Co., Philadelphia, expressed his understanding that few bus companies, aside from those operating in New York City, Chicago and Detroit, have made money. He made it plain that the street-railway industry must procure a vehicle that can be operated at a profit. Increase of fare means decrease of income. He did not express a definite opinion as to the future of the trackless-trolley-car but said that the regular bus is not what the street-railways need. A storage-battery vehicle, if practicable, would be very advantageous.

Prof. Morton Arendt, of Columbia University, appeared as a representative of New York City, and explained in a vivid and forceful manner what steps have been taken to meet transportation emergencies there. He said that in Baltimore the ordinary trolley, the bus and the trackless-trolley-car are being operated. There is a $2,500 annual tax on a 50-passenger bus. The fare is 10 cents. In New York City, due to the discontinuance of operation of several street-railway lines and the need for crosstown service, permits were issued for bus operation with 5-cent fare under certain stipulated regulations. In operation of these, which continued until it was enjoined by railroad corporations, no complaint was had from bus operators as to not making money on the 5-cent fare. The electric bus has a speed of from 11 to 12 m.p.h. and travels 45 miles on a charge. Professor Arendt said that a vehicle must be had in which the advantages in control of the electric vehicle and those of distance of the gas vehicle are available. The ordinary gasoline-bus is not the solution of transportation in sparse country, in his opinion. He cited the experience on Staten Island, where long routes over hills must be traveled and few passengers are to be transported. The cost per car-mile of the trackless-trolley-car there was $0.256 and of the gasoline truck $0.338. The former figure would be lower in handling a greater amount of traffic. Professor Arendt figures that the advantage is in favor of the trolley-bus to the extent of 10 cents per car-mile, there being no doubt that the overhead construction gives the cheapest transportation for undeveloped territory. He said that the increase in building along the routes of the trackless trolleys had been enormous, the gasoline bus not being so advantageous in this respect as it does not necessarily give promise of permanent operation in outlying districts.

Professor Arendt described and showed views of trackless-trolley-cars that had been designed specially for use in New York City, one design having a 195-in. wheelbase and capacity for 50 passengers, seats being provided for 30 of these. He said that he had seen over 75 people riding in one of these vehicles, which are well-sprung and have better acceleration than gasoline buses.

One very interesting thing Professor Arendt reported was that the City of New York is now installing a trackless-trolley system between the Pelham Bay subway station and City Island. At certain times, 16,000 people are transported per hour on this route. It is proposed that there shall be 25 trackless-trolley-cars in operation there.

Joseph A. Anglada advocated strongly the use of the electric vehicle in the mass transportation of passengers, citing its superiority with respect to long life, ease of control and low cost of maintenance. He mentioned the need for battery-charging sets on the electric vehicle.

Arthur J. Slade presented detailed information as to the trackless-trolley-cars that are being established in the suburbs of Paris, France; also of a new gasoline bus that is 34 ft. long and has three axles and six wheels, the weight being 300 lb. per passenger as compared with 600 in the case of the conventional trolley-car; and provision being made for 48 passengers, standing being permitted on the platform only.

The next meeting of the Metropolitan Section will be devoted to motor-truck operation. Edward E. La Schum, general superintendent of motor-vehicle equipment, American Railway Express Co., will read a paper on the Engineering Features of Fleet Operation. This meeting will be held at the Automobile Club of America on the evening of April 19 starting at 8 o'clock.

MID-WEST SECTION MEETINGS

The Mid-West Section met in Chicago on March 23 and was addressed by F. H. Ford on the subject of road-lighting. As a part of his presentation, Mr. Ford recommended a new type of chart for recording the relative anti-glare value and light distribution qualities of head-lamp lenses. Instead of representing light intensity by lines to indicate photometric values, Mr. Ford's arrangement denotes intensity by varying degrees of tints on the surface of a chart that is supposed to represent the roadway.

The next meeting of the Mid-West Section will be held at the rooms of the Western Society of Engineers, in the Monadnock Building, Chicago, on the evening of April 20. A paper will be read by J. G. Carroll on the General Design of Electric Trucks and Their Performance in Urban Work. This meeting will start at 8 o'clock.

MOTOR MARKET CONDITIONS CHANGING

Selection Replaces Mere Desire in the Psychology of Purchasing

Harry Tipper, business manager of *Automotive Industries*, brought out some interesting developments in the automotive industry on its economic side, in addressing the New England Section at its regular meeting in Boston on March 16.

Mr. Tipper called attention to the gradual change that has taken place in the buyer's reason for wanting a car and its effect on the builder's sales problem. Desire to possess was formerly the principal market, psychologically, for buying. Therefore the company that could deliver a product with sufficient rapidity was bound to get the business. Now the whole market is changing. The item of selection is coming to be more important than the mere possession of a car. That means that we shall have to explain more to the public and put a different kind of pressure in the market. Some firms are losing great possibilities of sales promotion by con-

sidering the business from the sales angle too much and not enough from the buyer's angle. Economically, we have to change the whole outlook and find out what the growing desire of the buyer will be.

Another consideration that enters into the production problem is the buyer's attitude regarding the used car. It is not likely he will trade unless he can trade at an advantage to himself. The time is coming when average new car sales will be less than 10 per cent. Practically all buyers of cars will be owners of other cars, and every sale will involve a transaction of trade. Dealers in Chicago said their figures indicated the sale of $250,000,000 worth of used cars last year. The actual profit on new cars would not be much more than that. It might be well to study other business lines that have the used product problem, such as typewriters, etc., where the mechanism is good for somebody long after the original purchaser has given it up. There is no separate market for new cars and used cars in the automobile business. If we have too many used cars on hand, the demand for new cars will decrease. We must have a proper proportion.

The great increase in the number of motor vehicles in use greatly increases the service problem and its possibilities. In 1913 there were 1,300,000 motor vehicles; on Jan. 1, 1923, there were 12,500,000. Service facilities must be increased in the next 5 or 6 years, and the problem must be studied from a more definite standpoint. There are approximately 600 models of cars out of production in operation in this Country, and some 400 companies make it their business to supply parts for cars that are not being produced regularly.

It will be found that the retailer tends to develop as the buyer's needs grow, and it is logical, therefore, that we should see, outside of the large cities, a strong development of business among retailers who specialize in the sale of supplies. The business of replacement every year constitutes a large per cent of the total requirement of necessities and parts. The man who wants to grow as a retailer with the business, will have to pay more attention to the replacement end of the business, and the manufacturer will have to give this branch of the industry some consideration also.

Mr. Tipper's address was followed by the complete seven-reel film "Electricity in the Motor Vehicle," produced by the North East Electric Co., showing graphically an outline of the development of electricity and its special use in the automobile.

A MOST IMPORTANT PROBLEM

WE believe that the great problems of highway transportation have received far less attention from automotive engineers than they deserve. Some of the remarks of A. J. Brosseau quoted below from a recent address emphasize this point.

> Transportation is, perhaps, the most vital factor in the lives of all of us. How much attention have you given it in your text-books and in your class-room work?
>
> How do you define transportation?
>
> Are you thinking of it as it was 20 years ago, when the railroad was the only carrier, or do you think of it in terms of the highly complex relationships of today, when we have highway, waterway, electric and steam rail lines, and very soon airways, to be correlated?
>
> Are you dealing with it as it will be in the future, when these agencies may overturn all of our accepted theories of economics, social life and political boundaries?
>
> Have you taken into account the fact that our highway transport has already injected new factors into our economics?
>
> Do you understand the relation between the highway and the vehicle and the important service they render to the public? Do you know that the highway and the vehicle together constitute a great factory, which produces the commodity we call transportation?
>
> Do you realize the importance of these factors in the financial scheme of things, and are you prepared to assist in developing sound theories not alone of finance, but of the actual physical structure of road and vehicle?
>
> Do you know that transportation is today the most important problem confronting the Nation, and, if we are to arrive at sound conclusions, is one that requires the best efforts of the most efficient research men obtainable?
>
> Has it ever occurred to you that the highways are not built for the individual owners, but for the public, and that the privately owned vehicles operating over the roads are in reality mere agencies for the convenience and comfort of this same public?

SULPHATION RATE OF STORAGE-BATTERY PLATES

STORAGE-BATTERIES have recently come into very extensive use particularly in connection with automobiles, and anything dealing with the proper method of caring for such batteries is, therefore, of considerable general interest. The life and efficiency of storage-batteries depend upon the purity of the materials used in constructing the plates and on the purity of the electrolyte. But little exact information is available on the effect of impurities in the solution that serves as the electrolyte, and the methods ordinarily employed for determining the effect of such impurities are time-consuming and often inaccurate.

A new method has been devised by the Bureau of Standards for measuring the rate of sulphation of the plates resulting from local action. This method is rapid and accurate but requires some special apparatus. By this method a study has been made of the rate of sulphation of both positive and negative plates in solutions of varying concentration. This is only the first step in a more extended investigation.

OBITUARY

WILLIAM MACGLASHAN, passenger-car engineer for the Studebaker Corporation of America, Detroit, died at his residence in that city Feb. 22, 1923, aged 46 years. He is survived by his wife and two daughters. He was born July 12, 1876, in Rothsey, Scotland, and received his general and technical education in Glasgow and the West of Scotland Technical College.

His early practical experience between 1894 and 1901 was with several manufacturing companies abroad; but in September, 1901, he became connected with the Winton Co., Cleveland, and continued in its service until March, 1903, at which time he was a designer. Following his European trip in 1903, he was chief draftsman and assistant engineer for the Winton Co. until April, 1912, then becoming chief engineer of the Studebaker Co., at South Bend, Ind., until July, 1913, when he came to Detroit in the interest of the same company. He was elected to Member grade in the Society, Dec. 22, 1913.

Current Standardization Work

ALTHOUGH the secretarial work of the S.A.E. Standards Committee necessitates sending out a large number of questionnaires and reports, a new system of circularization has been instituted which it is hoped will lessen the amount of work required of members in placing data and comments before the proper Divisions of the Standards Committee.

Information has been requested from every passenger-car, motor-truck and engine builder as to the proper individual to receive S.A.E. Standards correspondence. Addressograph plates giving the names and addresses of these individuals will be classified, by the use of a 24-place flag system, so that letters may be sent readily to only the particular companies interested in the subject matter of each letter. Thus it will be possible for a report of the Engine Division, for example, of interest to engine builders to be sent to the proper individuals connected with each engine company and passenger-car and motor-truck builders making their own engines.

As a closer contact will be established, only one follow-up letter will be sent out. This letter will call attention to the original letter and request an answer or acknowledgment. Follow-up letters are sent because it is recognized that frequently it is impossible to answer standards communications immediately and that they are put aside and sometimes overlooked.

In case standards communications on various subjects should be sent to different individuals in one company, the Society should be informed as such a division of correspondence can be taken care of easily.

Status of Important Subjects

The number following each of the subjects listed indicates the number of months its status has remained substantially unchanged. An asterisk means its status has changed during the last month.

AGRICULTURAL POWER EQUIPMENT DIVISION

C. B. Rose, *Chairman*

Tractor Belts and Pulleys (1)—Subdivision report awaiting Division action

Tractor Plowing Speeds (3)—Report to be submitted by O. B. Zimmerman

AXLE AND WHEELS DIVISION

C. C. Carlton, *Chairman*

Differential Gears *—Subdivision report to be submitted by S. O. White

Passenger-Car Front Axle Hubs (1)—Awaiting final Division action

BALL AND ROLLER BEARINGS DIVISION

F. W. Gurney, *Chairman*

Roller Bearings (1)—Subdivision report to be submitted by F. E. Moskovics

ELECTRIC VEHICLE DIVISION

E. L. Clark, *Chairman*

Battery Trays for Electric Trucks *—Awaiting Division action

Lamp Bulbs for Electric Vehicles (9)—Awaiting Division action

ELECTRICAL EQUIPMENT DIVISION

F. W. Andrew, *Chairman*

Magnet Wire (8)—Subdivision report to be submitted by Charles Marcus

ENGINE DIVISION

J. B. Fisher, *Chairman*

Engine Numbers (3)—Awaiting results of tests by Underwriters' Laboratories

Poppet Valves *—Subdivision report to be submitted by W. C. Willard. A progress report is contained elsewhere in this article.

FRAMES DIVISION

W. A. McKinley, *Chairman*

Motor-Truck Frames (5)—Subdivision report to be submitted by W. A. McKinley

IRON AND STEEL DIVISION

F. P. Gilligan, *Chairman*

Sheet Steel (1)—Subdivision report to be submitted by J. M. Watson

LIGHTING DIVISION

W. A. McKay, *Chairman*

Bases, Sockets and Connectors (10)—Subdivision report to be submitted by C. E. Godley

PARTS AND FITTINGS DIVISION

W. C. Keys, *Chairman*

Brake-Linings (23)—Report to be submitted by Subdivision

PASSENGER-CAR DIVISION

R. S. Begg, *Chairman*

Brake-Tests (10)—Report to be submitted by Subdivision

Frame Numbers (3)—Awaiting results of tests by Underwriters' Laboratories

PASSENGER-CAR BODY DIVISION

A. J. Neerken, *Chairman*

Aluminum Molding *—Awaiting report from W. D. Foote

Brass Molding *—Awaiting report from F. G. Smith

Paints, Varnishes and Enamels (2)—Subdivision report to be submitted by C. D. Holley

Steel Molding *—Awaiting report from E. W. Sellstrom

TRANSMISSION DIVISION

A. C. Bryan, *Chairman*

Clutch Standardization (11)—Subdivision report to be submitted by D. E. Gamble

TRUCK DIVISION

A. J. Scaife, *Chairman*

Motor-Truck Cabs (1)—Report awaiting final Division action

Annular Ball Bearings

At the Ball and Roller Bearing Division meeting held in April, 1922, the Division tentatively approved the adoption of the minimum corner-radii specified by the German Standards Committee in place of the radii specified in the present S.A.E. Standards for ball bearings.

Difficulty has since been experienced in changing over production to the corner radii specified by the German Standards Committee. It has developed that the corner radii are too large on most of the small sizes up to about bearing No. 212. There is not sufficient room for the standard rings

and further complications arise in the allowance for grinding. This subject will therefore be reopened at the next meeting of the Division.

Charging-Plugs and Receptacles

The following report on the subject of charging-plugs and receptacles, submitted by J. G. Carroll of the Electric Vehicle Division, will be discussed at the next meeting of the Division.

It is recommended that the following revisions be made in the S.A.E. Standard for Charging-Plugs and Receptacles, p. B38 of the S.A.E. Handbook:

The capacity of the smaller-size charging-plug and receptacle changed from 50 to 100 amp.

Dimension *J* of the smaller size changed from 1⅝ to 1⅛ in.

The note in reference to the capacity changed to read, "The National Board of Fire Underwriters has tested receptacles and plugs of the dimensions and ratings specified with an overload of 50 per cent."

In taking up the question of receptacles and plugs with various truck owners and garage operators, it became evident that there are objections to the use of the smaller size on street trucks on account of the desire for complete interchangeability of various trucks on all charging circuits. The majority of trucks have the larger size and the use of the smaller size tends to increase the difficulty of servicing. It is recommended that this question be referred to the Electric Vehicle Division for further consideration.

E. L. Clark has submitted a report on the standardization of battery trays for underslung compartments.

Lamp Voltage

W. A. Chryst, of the Dayton Engineering Laboratories Co., has raised the question of short life of lamp bulbs. Mr. Chryst's comments are appended hereinafter, together with abstracts of replies received commenting on his letter. The matter has been referred to the Lighting Division for consideration.

The Dayton Engineering Laboratories Co.

We are continually receiving complaints of short life of head-lamp bulbs. Most head-lamp bulbs are marked "6 to 8 volts," which might mean anything. As a matter of fact, in the winter time it is not uncommon for the battery voltage to rise to 8½ or 8¾ and sometimes even to 9 volts, as can be demonstrated readily by mounting a voltmeter on the dash and connecting it to the generator and the battery circuit. The voltage is especially high when the car is not kept in a warm garage.

The trend of legislation is insistence upon lenses and dimming devices to cut down the brilliance of the head-lamps and accordingly it seems that the lamp manufacturers are wrong when they try to get efficiency and high economy from lamp bulbs instead of long life and durability.

Automobile lighting conditions are not in any way parallel to those of commercial lighting, where efficiency and economy are of greatest importance.

W. A. Chryst, Chief Engineer.

Edison Lamp Works

The range of conditions in automobile service is enormous. The lamp manufacturers have carried on very careful voltage surveys covering thousands of cars, batteries and generating systems. In these surveys we have secured data showing the variation of the voltage at the lamp socket with the engine speed for different makes of car, different makes of generating system and cars of various ages of the same make.

We have secured data on the voltage-drop through the switches, the wiring and the sockets; and on the average lamp-load used under various conditions of driving, both city and country, summer and winter, on well lighted and poorly lighted streets and with cars parking; on the average mileage of cars in city and country driving; on the percentage of time the lamps are operated at the various speeds; on the condition of the storage-batteries in service; and on the charging rates of the various generating systems. In addition to this information we have listed the total number of cars of each make in use in the country. From this, the design voltage for various lamps that will give the best all-around average and most economical service to the consumer is figured out.

It would be practically impossible to furnish lamps that would be best for all of the various conditions. If we tried to furnish lamps to meet all of the possible conditions, and the varying characteristics of different makes this would unquestionably result in much inconvenience to the public; in many cases the wrong lamp would be supplied. The net result would be very poor service.

Twenty-one candlepower is required by law in a great many States. It is obvious that obtaining this, together with long lamp-life, would require a low-efficiency lamp that would consume a greater amount of current from the battery than the present lamps consume.

The slight saving in lamp renewals would not begin to offset the trouble and the cost of run-down batteries; we have trouble enough from that during cold weather at present. Also, long-life lamps would be initially so inefficient that at times when the battery voltage was low, their light would be insufficient to meet the legal requirements or to give a satisfactory driving-light.

L. C. Porter, Commercial Engineering Department.

General Motors Research Corporation

I am convinced that much can be done to assist the lighting situation by setting reasonable standards of construction for the lamps and the wiring.

Some lamp-makers are using steel sockets for the lamps, which rust. Steel reflectors are used without flexible connections, with the result that the rusting of the reflector stamping and of the steel clamps holding it give bad ground-connections. I suggest for consideration the possibility of standardizing some of the vital details of lamp construction. I imagine that the lamp-makers would have no objection to having improved standards set, and that the present situation is the result of too much "purchase-department engineering."

J. H. Hunt, Head of the Electrical Division.

Guide Motor Lamp Mfg. Co.

While I have no definite data on the subject, I believe that the higher-priced cars, on which are found the more efficient electrical circuits, have the most trouble with bulbs burning-out. In other words, the car builder who endeavors to decrease the resistance between the battery and the bulb is being penalized for his good intention by the fact that the majority of cars are not built with electric circuits of the same quality. Naturally, the bulb manufacturers make the bulbs to give the best average service, which, of course, is controlled by the medium-priced rather than the higher-priced cars.

C. A. Michel, Chief Engineer.

National Lamp Works

The few cars with which difficulty is experienced are in almost all cases cars in which a special effort has been made to keep the battery fully charged at all

times during the coldest weather, without regard to the service required of the car. In general, the charging rate is set so high that gassing of the battery takes place even with the full lighting-load turned-on. The characteristics of the lead-acid storage-battery are such that the voltage increases gradually until gassing starts, at which time a sharp voltage-rise occurs. Where the normal operating condition of the battery is a gassing one, abnormally high voltages at the lamps can be expected. The effect of gassing on the voltage can be readily demonstrated by cranking the engine with the ignition off for 1 min. on a car showing an extremely high voltage. This will discharge the battery slightly, but enough to eliminate gassing when charging again takes place and it will be found that the voltage at the lamps has dropped considerably.

Lamps are designed for a life materially longer than necessary to meet the average night-operation requirements of the average car for a period of 1 year. Satisfactory candlepower and life undoubtedly are obtained with a large proportion of the cars in service. High-voltage conditions give trouble in some cases but, on the other hand, serious difficulty is experienced in an even larger number of cases through insufficient candlepower. The need for adequate road illumination is expressed in an analysis of accidents by the State of Massachusetts showing that 25 per cent of all night-accidents in that State were due to improper lighting; 7½ per cent resulted from glare, and 17½ per cent were due to insufficient light. Low-candlepower conditions must be given due consideration as they have a most important bearing on the safety of the driver and his passengers. From its very nature, trouble from insufficient light does not present itself nearly as forcibly at a given time as does short lamp-life.

High-voltage difficulties have come up from time to time and in general have been remedied at the service-stations by turning on the maximum lighting-load for 5 or 6 hr. with the engine stopped to discharge the battery partially and also reducing the charging rate to a point where the battery is kept well charged, but below the gassing point when the lights are on. Another remedy that may appeal to the car builders and will give fairly satisfactory results if used intelligently is that of adding an extra point on the switch by which the motorist may insert a low resistance in the lighting circuit at times when the voltage conditions are so high as to cause trouble

The degree of satisfaction resulting with the above-named expedients will depend to a large extent upon the judgment exercised by the motorist. They simply tend to reduce rather than correct the difficulty. The real solution appears to be in the hands of the automobile builders through a decided reduction in the tremendous voltage-range now found in service. Voltage regulators in the battery-generator circuit appear to have possibilities that unfortunately can hardly be taken advantage of in cars already in service. Uniform voltage-conditions, however, cannot be expected unless the regulator is incorporated directly in the lighting circuit.

Aside from voltage regulators there are a number of things that the car builders could do to reduce the voltage range:

(1) Standardize the resistance in all electrical circuits with particular attention to the switches, the sockets, the fuses and their clips, the circuit-breakers, etc. Some idea of the need of such standardization may be gathered from the results of tests on cars equipped with 6 to 8-volt systems in which the voltage-drops from the batteries to the head-lamps varied from 0.21 to 1.43 volts

(2) Provide generators and batteries of sufficient capacity to keep the batteries reasonably well charged under all ordinary temperature conditions

(3) Provide generators with characteristics such that the cut-in occurs at a fairly low car-speed and the maximum charging-current is reached at or below average driving speeds

(4) Replace the dimming resistance in the head-lamp circuits with 2-cp. side or auxiliary lamps to assist in keeping the batteries charged in case the drivers park considerably more than the average time

(5) Issue uniform instructions to service-stations regarding charging adjustments

H. H. MAGDSICK.

White Motor Co.

We believe that the bulb bases, the sockets, the bayonet locks, the connectors and other parts should have not only less electrical resistance but greater mechanical strength.

The bulb failure in automobile lighting, especially on trucks and buses, is, we believe, due primarily to the frail mechanical principles employed in the design. There is not a lamp manufacturer today using good, rigid substantial bulb-sockets or connectors.

A. J. SCAIFE, Chief Factory Service Engineer.

POPPET VALVES

In August 1922 a Subdivision of the Engine Division was appointed to revise and extend the present S.A.E. Standard for Poppet Valves, p. A4 of the S.A.E. HANDBOOK. W. S. Willard was appointed chairman, the other members being J. B. Fisher, of the Waukesha Motor Co., W. H. Spire, of Steel Products Co., and M. W. Wilcox, of the Wilcox Motor Mfg. Co.

A preliminary report was submitted recently for the consideration of the engine builders. If it meets with general approval, it will be transmitted to the engine Division for approval. The preliminary report of the Subdivision follows:

POPPET VALVES WITH CAST IRON HEADS

(1) Poppet-valve sizes, known by the diameter of the ports that they close, shall vary by increments of ⅛ in.

(2) The outside diameter of a valve shall exceed the largest diameter of the cylinder-seat by amounts shown in the accompanying table. The small diameter of the valve-seat shall be less than the port-diameter by 1/32 in.

(3) The over-all length shall be considered as being measured from the top of the valve-seat to the tip of the stem

(4) The position and the length of the valve-stem guide with the valve in its closed position, shall be shown on all valve drawings as indicated in the accompanying illustration

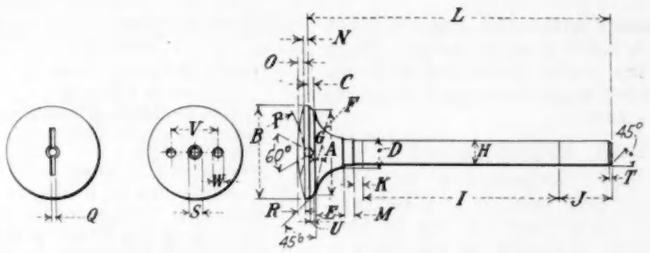
(5) The specified stem-diameter limts shall be measured within this guide position and shall apply to that portion of the stem only

(6) There shall be a chamfer on the tip of valve-stems whose angle shall be 45 deg. with the center-line of the valve and whose width shall be as given in the accompanying table

(7) There shall be a minimum length of unfinished stem-stock projecting below the head of 3/32 in.

(8) There shall be a ground clearance-length between the top of the valve-stem guide position and the unfinished-stem portion of not less than ⅛ in.

(9) There shall be a standard method of inspecting and measuring the truth of the valve-seat with respect to the valve-stem. The method shall consist of rolling the valve in V-blocks placed within the limits of the valve-stem guide position while the valve is held against a fixed stop bearing against the center of the tip of the valve-stem.



DIMENSIONS FOR CAST-IRON-HEAD POPPET-VALVES

Nominal Diameter A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	Drill Diameter W
1	1 5/32	5/64	11/32	1/4	1/4	7 1/2	0.2470	Length of Valve-Stem Guide	Position of Guide, Valve Closed	Ground Clearance Above Guide	Valve Length Specified in Even 1/4"	Rough-Stem Length 3/32" Minimum	1/16	1/16	2 3/4	1/16	1/16	3/16	1/32	3/64	1/2	5/64
1 1/8	1 9/32	5/64	11/32	1/4	1/4	7 1/2	0.2470						1/16	1/16	2 3/4	1/16	1/16	3/16	1/32	3/64	1/2	5/64
1 1/4	1 13/32	5/64	11/32	7/16	7/16	7 1/2	0.3095						1/16	1/16	2 3/4	1/16	1/16	3/16	1/32	3/64	1/2	5/64
1 3/8	1 17/32	5/64	7/16	7/16	7/16	7 1/2	0.3095						1/16	3/32	2 3/4	1/16	3/32	3/16	1/32	3/64	3/4	5/64
1 1/2	1 11/16	3/32	17/32	15/32	15/32	7 1/2	0.3720						1/16	3/32	2 3/4	1/16	3/32	1/16	1/32	1/16	3/4	3/32
1 5/8	1 13/16	3/32	17/32	15/32	15/32	7 1/2	0.3720						3/64	7/64	2 3/4	1/16	3/32	1/16	1/32	1/16	3/4	3/32
1 3/4	1 15/16	3/32	17/32	15/32	15/32	7 1/2	0.3720						3/64	7/64	2 3/4	1/16	1/8	1/32	1/32	1/16	3/4	3/32
1 7/8	2 1/16	3/32	17/32	15/32	15/32	7 1/2	0.3720						3/64	7/64	2 3/4	3/32	1/8	1/32	1/32	1/16	3/4	3/32
2	2 1/4	1/8	5/8	5/8	5/8	15	0.4340						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	1/16	3/4	3/32
2 1/8	2 3/8	1/8	5/8	5/8	5/8	15	0.4340						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	3/4	3/32
2 1/4	2 1/2	1/8	5/8	5/8	5/8	15	0.4340						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	3/4	3/32
2 3/8	2 5/8	5/32	11/16	13/16	13/16	15	0.4960						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	3/4	3/32
2 1/2	2 13/16	5/32	11/16	13/16	13/16	15	0.4960						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	1/8	1	3/32
2 5/8	2 15/16	5/32	11/16	13/16	13/16	15	0.4960						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	1/8	1	3/32
2 3/4	3 1/16	5/32	7/8	1	1	15	0.6210						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	1/8	1	3/32
2 7/8	3 3/16	5/32	7/8	1	1	15	0.6210						3/32	3/32	2 3/4	3/32	1/8	1/32	1/32	3/64	1/8	1	3/32
3	3 3/8	1/16	1 1/8	1 5/16	1 5/16	22 1/2	0.7450						1/8	3/16	2 3/4	1/8	3/16	1/4	3/32	5/32	1 1/4	3/16

Heads may be crowned or flat; if flat, *G* should be increased by 7½ deg.
Fractional dimensions take ± 0.010-in. limits.
Seat must be true and concentric with stem within 0.003-in. indicator reading by standard method of inspection.
Stem diameters shall be gaged with limit gages.
Stem diameters are based on S. A. E. Steel No. 1020.

The indicator shall bear against the valve-seat and its readings taken while the valve is rotated

(10) The seat angle shall be 45 deg. with the center-line of the valve

(11) Where a slot is used in the valve-head for the purpose of grinding, its dimensions shall be as shown in the accompanying table. Two drilled holes may be used as optional design for this purpose, in which case their dimensions shall be as shown

(12) Valve-stem tips shall be case-hardened before finish-grinding the stem and should show a scleroscope hardness of 45 plus

(13) Valve-stem lengths shall vary by increments of ¼ in.

(14) Fractional dimensions shall be subject to limits of plus and minus 0.010 in.

(15) Valve-stem lengths shall be specified in fractional dimensions

(16) Valve-stem diameters shall take machining limits of plus and minus 0.0005 in., as specified in (5), these limits to be inspected by "snap gages" or equivalent means

(17) Valve-seats must run true with valve-stems as specified in (9), within 0.003-in. indicator reading and shall be free from visible chatters

(18) Valve-head dimensions shall be as specified in the accompanying table

(19) The type of spring-retaining mechanism used shall be optional

Sheet Steel

The Committee on Testing Sheet Steel, which is working under the Sheet Steel Subdivision of the Iron and Steel Division, has held several meetings to formulate methods of testing sheet steel that will be used as a basis for a sheet-steel standard.

Stationary-Engine Belt-Speeds

At the last meeting of the Stationary-Engine Division the work that has been done on the standardization of stationary engine belt-speeds was reviewed and the following recommendation approved as tentative S.A.E. Recommended Practice.

STATIONARY-ENGINE BELT-SPEEDS

Rated Engine Power, Hp.	Belt Speed, Ft. per Min.
1½	600
2	750
3	950
4	1,125
5	1,275
6	1,400
7	1,500
8	1,600
9	1,650
10	1,700
12	1,800
15	1,900

The belt speeds for *portable* engines of 10 hp. and larger shall be 2600 ft. per min., tractor belt-speed standard.
The variation in belt speeds shall not exceed 5 per cent above or below those specified.

March 1923 Issue of Data Sheets

The March 1923 issue of data sheets for the S.A.E. Handbook will be sent to the members early in April. It is important that members using the S.A.E. Handbook in their work should check their Handbooks so that they may be sure that all, as well as the most recent, sheets issued to date have been inserted properly. A check list of all the S.A.E.

HANDBOOK pages and their latest publication dates is given on the first sheet of the March issue of data sheets. These dates should be checked to the dates under the emblems appearing at the bottom of each right-hand data sheet to verify completeness and up-to-dateness.

REPORT ON SEMI-ANNUAL LETTER-BALLOT

The proposed standards and recommended practices printed on p. 529 of the December 1922 issue of THE JOURNAL and approved at the Standards Committee Meeting in New York City on Jan. 9, 1923, were approved by the Society Members in the letter balloting that closed on March 12. The complete vote on all of the recommendations considered is recorded in the accompanying table. The first column gives the number of affirmative votes; the second column the number of negative votes; and the third column the number of Members who do not vote either way.

Subject	*Yes*	*No*	*Not Voting*
Passenger-Car Front-Axle Hubs	152	3	163
Roller Chains and Roller-Chain Sprockets	112	0	206
Electric Vehicle Motors	76	0	242
Generator Flange Mountings	165	0	153
Starting-Motor Flange Mountings (Outboard Type)	162	0	156
Starting-Motor Flange Mountings (Inboard Type)	161	0	157
Starting-Motor Pinions	158	0	160
Magneto Mountings	154	0	164
Spark-Plugs	170	2	146
Flywheel Housings	158	0	160
Running-Board Brackets	135	1	182
Iron and Steel Specifications	193	2	123
Electric Incandescent Lamps	144	2	172
Tail-Lamp Illumination	136	1	181
Crankcase Lubricating Oils	137	9	172
Automobile Nomenclature	188	2	128
Plain Washers	180	0	138
Rod-Ends	176	1	141
Door-Locks and Handles	104	1	213
Wood-Screws	112	1	205
Plate Glass	103	2	213
Gages and Gaging	169	0	149
Ratings of Storage-Batteries for Isolated Electric-Lighting Plants	103	3	212
Storage-Battery Monobloc Containers	103	2	213
Clutch Facings	155	0	163
Vertical Dumping-Hoist Platforms	98	1	220
Three-Joint Propeller-Shafts	117	1	200
Body Hold-Down Clamps	113	2	203

LIVING-WAGE FOR FARMERS

WHEN the industrial worker gets a grasp on the fact that farming as an industry is four times greater than the railroads of America, so far as the capital invested is concerned, his respect for the magnitude of the farming industry is bound to be somewhat increased. In 1921 there were 1,580,000 railroad workers in this Country, as against 10,674,534 employed on farms. The total number of men employed in iron and steel mills and plants making iron and steel products, like machinery and hardware, is but 1,585,712. In short, more than one-fourth the persons engaged in gainful occupations in this Country are on farms.

There are 121,040 industries that depend upon the farmer for their raw materials; they employ 3,074,798 wage-workers, to whom they pay $3,091,157,771 in wages. The output of these industries is valued at $27,560,583,389.

In 1921 the average return of the farmers of the United States for labor, risk and management was $183! At 5 per cent the interest on his investment averaged $610, making a total of $793. But the only figure calling for a comparison with the wages of the industrial worker is $183. In 1921 the average earning of the railroad-shop worker was $1,506, or more than eight times what the average farmer received for his labor. The miner did still better, scoring an average of $1,779. And yet we heard considerable from the railroad-shop worker and the miner about the fact that they were not being paid a "living-wage."

Legislation is needed to remove certain handicaps under which the farmer is laboring, but that will not restore the balance between the farmer's reward and the industrial wage-worker's pay-check. It will merely help a little. The farmer needs all the little helps he can get. And he is in a position to get about what he insists upon in the way of legislation from the present Congress. If legislation could insure his prosperity he soon would be on the high road toward that much to be desired goal.

There is undoubtedly a strong inclination on the part of farmers who intend to continue in production to cut down its volume. What is perhaps more to the point is the fact that thousands upon thousands of farmers have lately deserted farming and sought jobs in industry. The desertion from the ranks of farmers since 1920 has been on a wholesale scale. But even in 1920 there were 1,573,543 fewer people on the farms of this Country than in 1910, in spite of our huge population increase. This process of farm desertion is bound to continue until Europe is again a good and active buyer of American farm products. The thinking farmer has a settled conviction that it will be a long time before Europe will afford him much nourishment as a customer for farm products. He is not counting on that outlet and his mind is decidedly busy with the problems of decreased production. He is inclined to feel that he has been very busy "killing the job," as the union worker puts it, and that it is about time for him to pass up to the industrial worker the same brand of output restriction that the organized worker in industry has been passing to his employer. The farmer is thinking of "slowing down," too. Respecting the readjustments of freight rates, so as to shift some of the burden now resting on raw materials from the farm to the shoulders of fabricated products carrying the cost of industrial labor, the farmer can and will exert a powerful pressure and will probably secure substantial results.

There is one outstanding tendency among all farmers, that of giving less thought to production and more to marketing. They have acquired a stubborn conviction that somehow they will have more to say than heretofore about the prices at which they sell their products. Some have rather wild theories as to how this may be accomplished. But there is a strong mass determination to achieve this end by any and every means possible.—Forrest Crissey in *Journal of the American Bankers Association.*

Applicants *for* Membership

The applications for membership received between Feb. 15 and March 15, 1923, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

ADAMS, JAMES R., superintendent of research department and plant metallurgist, Midvale Steel & Ordnance Co., *Philadelphia.*

AITKEN, LEON L., chief tool designer, Fuller & Sons Mfg. Co., *Kalamazoo, Mich.*

ARNOLD, CHARLES F., student, University of Cincinnati, *Cincinnati.*

BALLENTINE, WILLIAM I., vice-president, Advance-Rumely Co., *La Porte, Ind.*

BENDER, E. J., service engineer, Yellow Cab Mfg. Co., *Chicago.*

BLACKMORE, CHARLES C., owner, Charles C. Blackmore Co., *Dayton, Ohio.*

BURKE, EDMUND, salesman and correspondent, Motometer Co., *Long Island City, N. Y.*

CARLSON, CLIFFORD E., student, University of Cincinnati, *Cincinnati.*

CARTER, H. A., vice-president and sales manager, George R. Carter Co., *Connersville, Ind.*

CONNELLY, FRANK HAROLD, student, Tri-State College, *Angola, Ind.*

COOLEY, C. STEWART, student, University of Cincinnati, *Cincinnati.*

CRAVEN, A. R., student, University of Cincinnati, *Cincinnati.*

CUSHMAN, E. H., automotive engineer and assistant manager, Myron D. Kidder, Inc., *Portland, Me.*

DAVIS, M. MOSS, mechanic, Missouri Motor Co., *Columbia, Mo.*

DAY, AUSTIN W., student, University of Cincinnati, *Cincinnati.*

DETTLINGER, FRED. W., laboratory engineer, Plant 5, Studebaker Corporation of America, *Detroit.*

DRESSER, SIDNEY R., cable engineer, Whitney Blake Co., *New York City.*

DUNBAR, FRANK, student, University of Cincinnati, *Cincinnati.*

DURHAM, SAMUEL M., student, University of Cincinnati, *Cincinnati.*

DWIGANS, ROGER W., student, University of Cincinnati, *Cincinnati.*

DWYER, C. EUSTACE, sales engineer, Timken-Detroit Axle Co., *Detroit.*

EARLE, ERNEST A., engineer and designer, Arrow Head Steel Products Co., *Minneapolis.*

EVANS, R. K., sales engineer, Remy Electric Co., *Anderson, Ind.*

FISHLEIGH, CLARENCE T., engineer in charge of experimental engine testing, American Car & Foundry Co., *Chicago.*

FROST, LEON E., student, University of Michigan, *Ann Arbor, Mich.*

GARDNER, F. P., engineer, 111 Broadway, *New York City.*

GARRARD, L. A., research engineer, Standard Oil Co. of New York, *New York City.*

GASSIN, HENRY P., tool designer, International Motor Co., *New Brunswick, N. J.*

GESREGAN, C. WESLEY, sales manager, National Lead Co., *New York City.*

GILLET, CHARLES C., district sales manager, Seamans & Cobb Co., *Detroit.*

GOSS, RICHARD M., student, University of Cincinnati, *Cincinnati.*

GRANER, ADOLF, president, Wisconsin Magneto Co., *Milwaukee.*

GRASS, ALBURN R., student, University of Cincinnati, *Cincinnati.*

GROSS, EDWARD H., sales manager, Donning Carburetor Corporation, *Bridgeport, Conn.*

HAMILTON, GEOFFREY JOHN, student, Cornell University, *Ithaca, N. Y.*

HANFORD, L. T., general sales manager, Paige-Detroit Co., of New York, *New York City.*

HANSELL, HOWARD FOSTER, student, University of Cincinnati, *Cincinnati.*

HAWLEY, FRANK M., engineer, Morse Chain Co., *Detroit.*

HENDERSON, CHARLES E., local purchasing agent, Air Mail Service, *Maywood, Ill.*

HENRY, HOWARD W., chief engineer, Klaxon Co., *Newark, N. J.*

HERSHAM, CONRAD O., tool designer, International Motor Co., *New Brunswick, N. J.*

HODTUM, CLARENCE, student, University of Cincinnati, *Cincinnati.*

HOELSCHER, ROBERT J., student, University of Cincinnati, *Cincinnati.*

HOLLAND, MAURICE, chief of industrial engineering, engineering division, Air Service, McCook Feld, *Dayton, Ohio.*

HOLMES, GEORGE ARTHUR, student, University of Michigan, *Ann Arbor, Mich.*

HUBBARD, GLENN W., engineer, Chalmers plant, Maxwell Motor Corporation, *Detroit.*

HULING, JOSEPH B., foreman, International Harvester Co., *Springfield, Ohio.*

INGALLS, PHINEAS H., student, University of Cincinnati, *Cincinnati.*

KINSEY, KENNETH HARRY, student, Purdue University, *Lafayette, Ind.*

KIRBY, RALPH L., student, University of Cincinnati, *Cincinnati.*

LEAVER, GEORGE ALBERT CHARLES, consulting automotive engineer, A. J. Leaver & G. A. C. Leaver, *Brisbane, Queensland, Australia.*

LUIGGI, MARIO LUIGI, mechanical and civil engineer, American representative of R. Garrett & Sons, Leiston, England, 56 East 87th Street, *New York City.*

LYNCH, W. ROSWELL, sales engineer, Gray & Davis, Inc., *Boston.*

MCARDLE, JAMES P., retail salesman, General Motor Truck Co., *Chicago.*

MANDEVILLE, GEORGE S., JR., student, University of Cincinnati, *Cincinnati.*

MARSHALL, A. F., experimental engineer, R & V Motor Co., *East Moline, Ill.*

MATHER, JUDSON, student, University of Cincinnati, *Cincinnati.*

MONTGOMERY, EDMOND, automobile engineer, Palace Hotel, *Port Chester, N. Y.*

NELSON, CHARLES, JR., draftsman, Western Electric Co., Inc., *Hawthorne, Ill.*

PORTER, R. C., engineer, Stromberg Motor Devices Co., *New York City.*

RAIFSNYDER, F. H., student, Ohio Northern University, *Ada, Ohio.*

RALPH, HORACE F., student, University of Cincinnati, *Cincinnati.*

ROSS, WALTER D., student, Purdue University, *West Lafayette, Ind.*

STEVENS, F. W., associate physicist, Bureau of Standards, *City of Washington.*

SHUSTER, WILBUR W., student, University of Cincinnati, *Cincinnati.*

SMEDLEY, ELMORE H., student, University of Cincinnati, *Cincinnati.*

STOWE, GEORGE, vice-president and general manager, Reo Motor Car Co., *New York City.*

TEACHOUT, J. HOWARD, production manager, White Motor Co., *Cleveland.*

TROUANT, VIRGIL E., engineer, Westinghouse Electric & Mfg. Co., *East Pittsburgh, Pa.*

UPHAM, E. W., chief metallurgist, Maxwell Motor Corporation, *Detroit.*

WARREN, KENNETH WILLIAMS, student, Stevens Institute of Technology, *Hoboken, N. J.*

WEISEL, WILLIS L., student, University of Cincinnati, *Cincinnati.*

WHITE, HENRY J., assistant experimental engineer, International Motor Co., *New York City.*

WILBURN, JOHN PAUL, sales engineer, Prest-O-Lite Co., Inc., *Indianapolis.*

ZEDER, JAMES C., layout work, specification department, Timken Roller Bearing Co., *Canton, Ohio.*

Applicants *Qualified*

The following applicants have qualified for admission to the Society between Feb. 10 and March 10, 1923. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

ALLISON, FRED (M) electrical engineer and superintendent of power, Ford Motor Co., Detroit, (mail) 125 Moss Avenue, *Highland Park, Mich.*

BUTZ, JOSEPH E. (M) research engineer, General Motors Research Corporation, *Dayton, Ohio.*

CHERNIACK, NATHAN (J) assistant transportation engineer, Ward Motor Vehicle Co., Mount Vernon, N. Y., (mail) 332 Osborn Street, *Brooklyn, N. Y.*

CLARK WILLARD T. (A) resident partner, Henry W. Peabody & Co., Bartoleme Mitre 1746, *Buenos Aires, Argentina, South America.*

COOKE, B. W. (A) president, Cooke Automobile School and Coyne Trade & Engineering School, 1300 West Harrison Street, *Chicago.*

CROWE, G. FRANCIS (E S) student, University of Toronto, *Toronto, Ont., Canada,* (mail) South Residence, University of Toronto.

DAVENPORT, GEORGE R. (M) special engineer, Studebaker Corporation of America, Detroit, (mail) 226 Austin Avenue, *Royal Oak, Mich.*

DAVIDSON, COLEMAN LAWSON (E S) student, Georgia Institute of Technology, *Atlanta, Ga.,* (mail) 53 Cherry Street.

DELANEY, GEORGE A. (A) engineer, Paige-Detroit Motor Car Co., *Detroit.*

DESCHAMPS, ROGER P. (A) manager, Standard Automobile Co., *Brussels, Belgium,* (mail) 102, Chaussee D'Anvers.

DOWNES, GEORGE Q., JR. (E S) student, Ohio State University, *Columbus, Ohio,* (mail) 137 Chittenden Avenue.

DUFFEE, FLOYD W. (A) assistant professor, University of Wisconsin, *Madison, Wis.*

ERNST, OTTO (A) dentist and inventor, 83 Larchmont Avenue, *Larchmont, N. Y.*

EVENBURGH, R. L. (J) 747 Belden Avenue, *Chicago.*

FENN, GEORGE PRENTICE (E S) student, University of Illinois, Urbana, Ill., (mail) 404 East Daniel Street, *Champaign, Ill.*

FIELD, FRANK JAMES (F M) chief engineer, Feroda Ltd., Sovereign Mills, *Chapel-en-le Frith, Derbyshire, England.*

GEISSE, JOHN HARLIN (S M) engineer, Aeromarine Plane & Motor Co., Keyport, N. J., (mail) 3432 Connecticut Avenue, *City of Washington.*

GOODFRIEND, I. F. (E S) student, Columbia University, *New York City,* (mail) Fernald Hall, Columbia University.

GUSTAFSSON, BIRGER G. (A) tool and die designer, Arvac Mfg. Co., *Anderson, Ind.,* (mail) 207 West Ninth Street.

HAUTZENROEDER, RICHARD WAGNER (J) draftsman, Aultman-Taylor Machinery Co., *Mansfield, Ohio,* (mail) 291 West Third Street.

HOLMES, LAWRENCE J. (M) factory manager, International Motor Co., *Allentown, Pa.,* (mail) 128 South 17th Street.

HOLOWAY, PERCIE U. (A) estimator and service salesman, Donovan Motor Car Co., Boston, (mail) 374 Main Street, *Wakefield, Mass.*

HOPKINS, FRED J. (J) designer, International Harvester Co. of America, *Chicago,* (mail) 3402 Flournoy Street.

INGALS, E. FLETCHER, 2ND (J) student, Massachusetts Institute of Technology, *Cambridge, Mass,,* (mail) 1572 Massachusetts Avenue.

IRVIN, W. A. (A) assistant to the vice-president, American Sheet & Tin Plate Co., Frick Building, *Pittsburgh.*

LAUER, CARLETON J. (M) experimental engineer, Doble-Detroit Steam Motors Co., *Detroit,* (mail) 1671 Clairmount Avenue.

LEISTER, FAYETTE (A) sales engineer, Fafnir Bearing Co., New Britain, Conn., (mail) 489 James Street, *Syracuse, N. Y.*

LOCKWOOD, RALPH G. (A) patent lawyer, Lockwood & Lockwood, 1210 Fletchers Savings & Trust Building, *Indianapolis.*

MACLELLAN, W. ADAIR (A) assistant engineer, British Bock Bearings Ltd., 120 Cornwall Street, *Glasgow, Scotland.*

MAHER, GEORGE A. (A) manager, C. M. Hall Lamp Co., *Kenosha, Wis.*

MALCHOW, HENRY J. (A) division engineer, Standard Oil Co., *Milwaukee,* (mail) 1007 First Street.

MARSH, WILLIAM B. (A) superintendent, Locomobile Co. of Illinois, Inc., 515 East 27th Street, *Chicago.*

MEADER, GLENN S. (J) student, University of Minnesota, *Minneapolis,* (mail) 4740 Fremont Ave., South.

METZ, ALBERT G. (A) editor, Chilton Co., 49th and Market Streets, *Philadelphia.*

MIDDLEKAUF, EDISON B. (A) automotive purchasing agent, Texas Co., 90 West Street, *New York City.*

MILWARD, W. F. (F M) chief engineer, W. S. Laycock, Ltd., Millhouses, *Sheffield, England,* (mail) Endcliffe Crescent.

NAFZGER, EDWIN (M) designing engineer, Koppel Industrial Car & Equipment Co., *Koppel, Pa.,* (mail) P. O. Box 222.

NIELSON, MORITZ (M) Phelps Light & Power Co., Rock Island, Ill., (mail) 11536 Normal Avenue, *Chicago.*

PERKINS, ERNEST DELLA (E S) student, University of Michigan, *Ann Arbor, Mich.,* (mail) 603 East Ann Street.

PETERS, JENNINGS D. (J) student, University of Washington, *Seattle, Wash,* (mail) Terry Hall, University of Washington.

PLEISS, PAUL (A) secretary and director, Budd Wheel Co., *Philadelphia.*

RACKMAN, GEORGE JOHN (M) chief engineer, Yellow Coach Mfg. Co., *Chicago,* (mail) 1148 Belden Avenue.

RAGSDALE, EDWARD T. (J) draftsman, Pierce-Arrow Motor Car Co., *Buffalo,* (mail) 40 Custer Street.

RAHUSEN, E. N. (M) manager, Handelsbureau voor Automobiel & Vliegtuig Industrie, 39 Oranjelaan, Ryswyk, Z. H., Holland, (mail) Zella-Mehlis, Szawe Automobile Co., *Thuringia, Germany.*

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